CMS Future Plans

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Princeton University
(on behalf of CMS)

Snowmass Energy Frontier Workshop
July 1, 2013

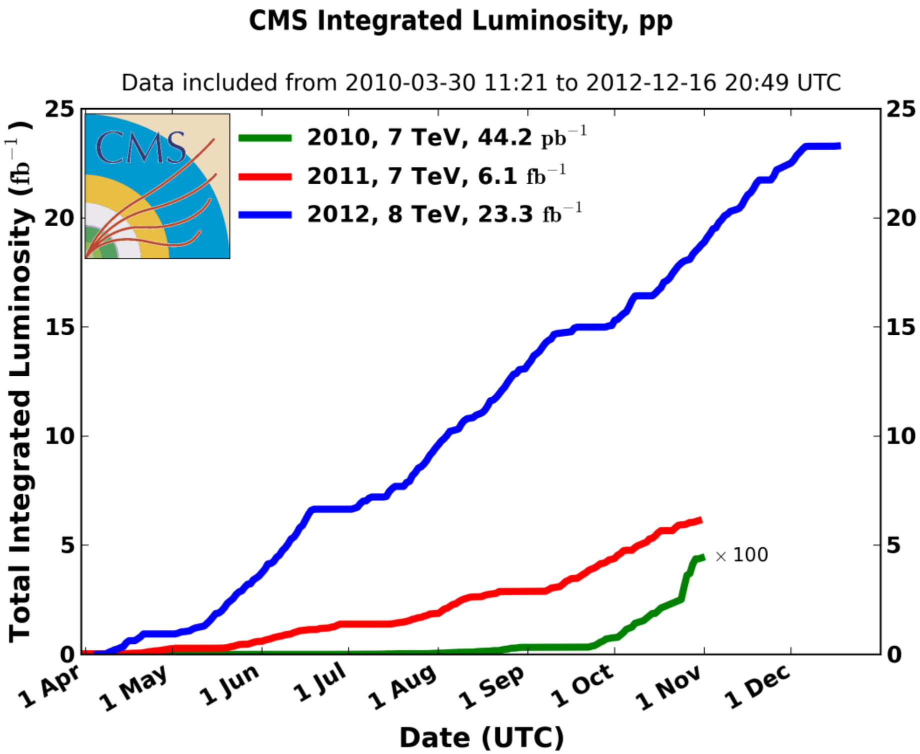
Outline

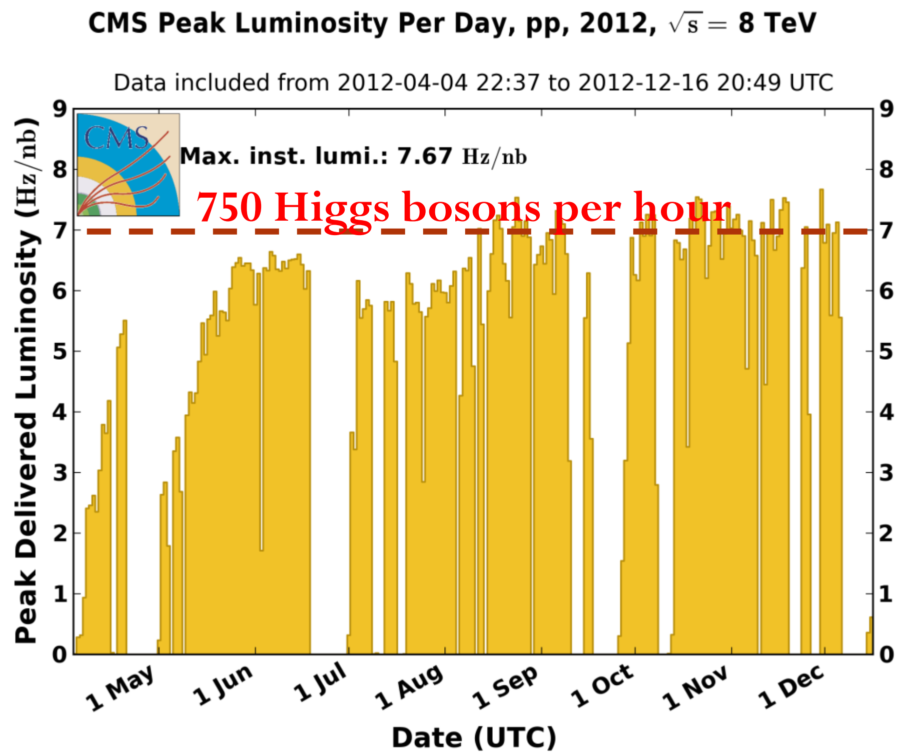
- **Motivation**
  - LHC status and future opportunities
  - Future CMS detector challenges
- **CMS upgrades**
  - LS1 and Phase 1 plans
  - Phase 2 paths
- **CMS physics potential at 14 TeV: new results**
  - Precision Higgs physics
  - Discovery potential: SUSY particles and exotic heavy resonances
- **CMS plans for Snowmass and beyond**
- **Summary**

Motivation

LHC and CMS Performance

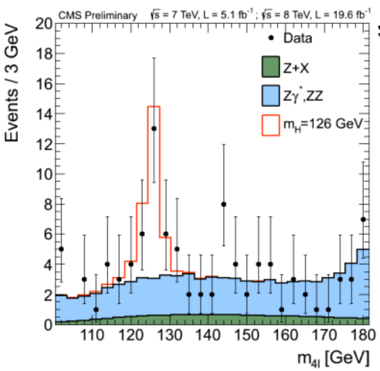
Integrated pp luminosity delivered to (recorded by) CMS: 30 (27) fb^{-1}

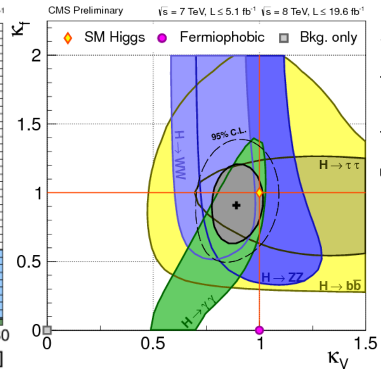


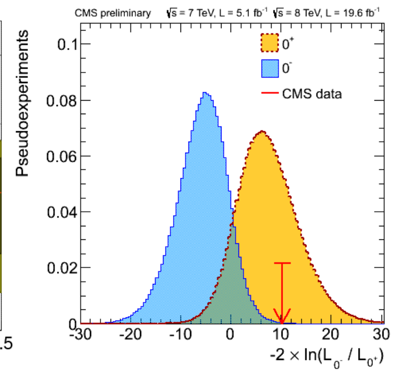


Amazing LHC performance, robust detector operation

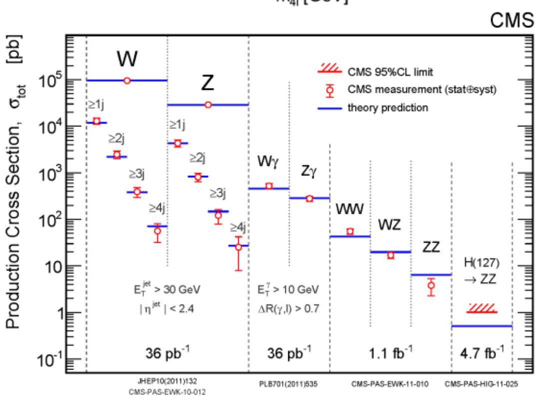
Energy Frontier Landscape

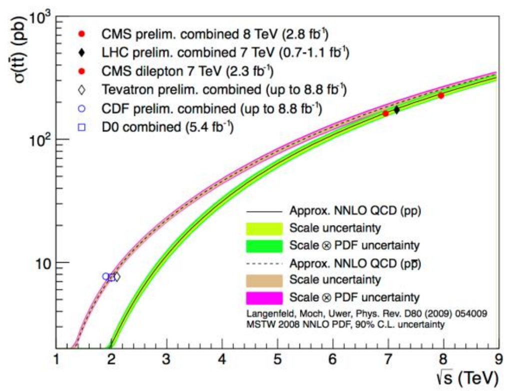




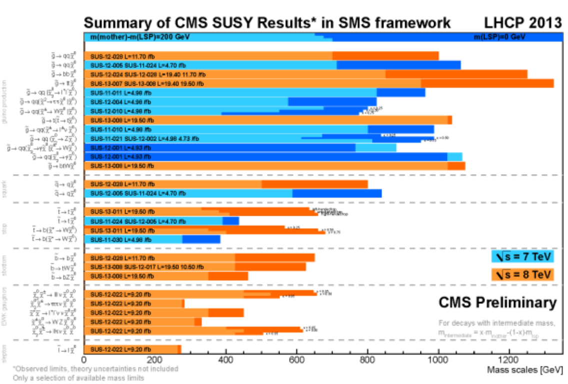


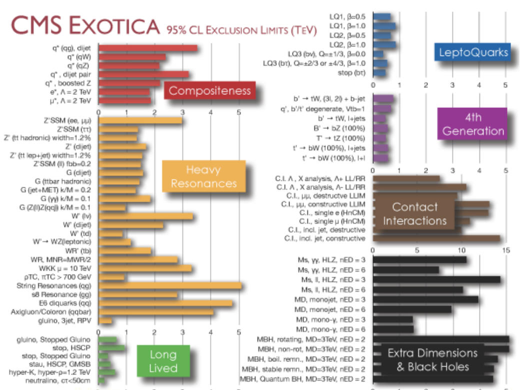
Discovery of a Higgs boson





Precision SM measurements consistent with expectation



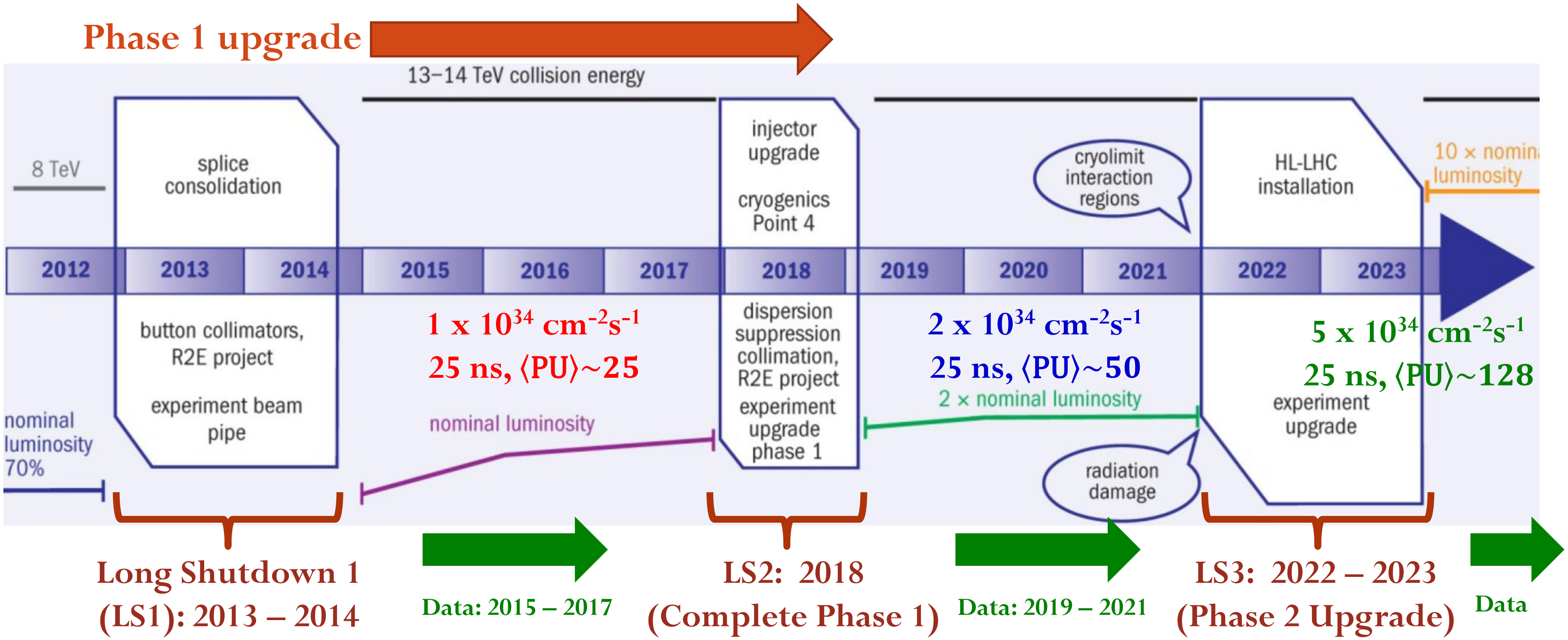


No sign of sparticles or exotic heavy resonances

Motivation for LHC Future

- **LHC (14 TeV): 2015 – 2021**
  - Doubling of new particle mass reach: SUSY and/or Exotic discovery
  - Higgs properties: mass, spin, width, couplings, exotic/rare decays
  - Search for additional Higgs bosons above and below 126 GeV
  - VV scattering at high energy
  - Measurement of rare SM processes
- **High Luminosity (HL-LHC): 2024 – 2030s**
  - Characterization of new particles discovered in Phase 1, or
  - Extension of new particle mass reach
  - Precision Higgs measurements: couplings, self-coupling
  - Search for new Higgs bosons up to (and beyond) 1 TeV
  - Precision measurements of rare SM processes

LHC Future: from here to there



- **LHC:**
  - Reach 1x design lumi by LS2, 2x design by LS3, and integrate 300 fb^{-1} by 2022
  - pile-up (PU) = 50-100
- **HL-LHC:**
  - Lumi-level at 5x design and integrate 3000 fb^{-1}
  - use PU=140 for upgrade studies

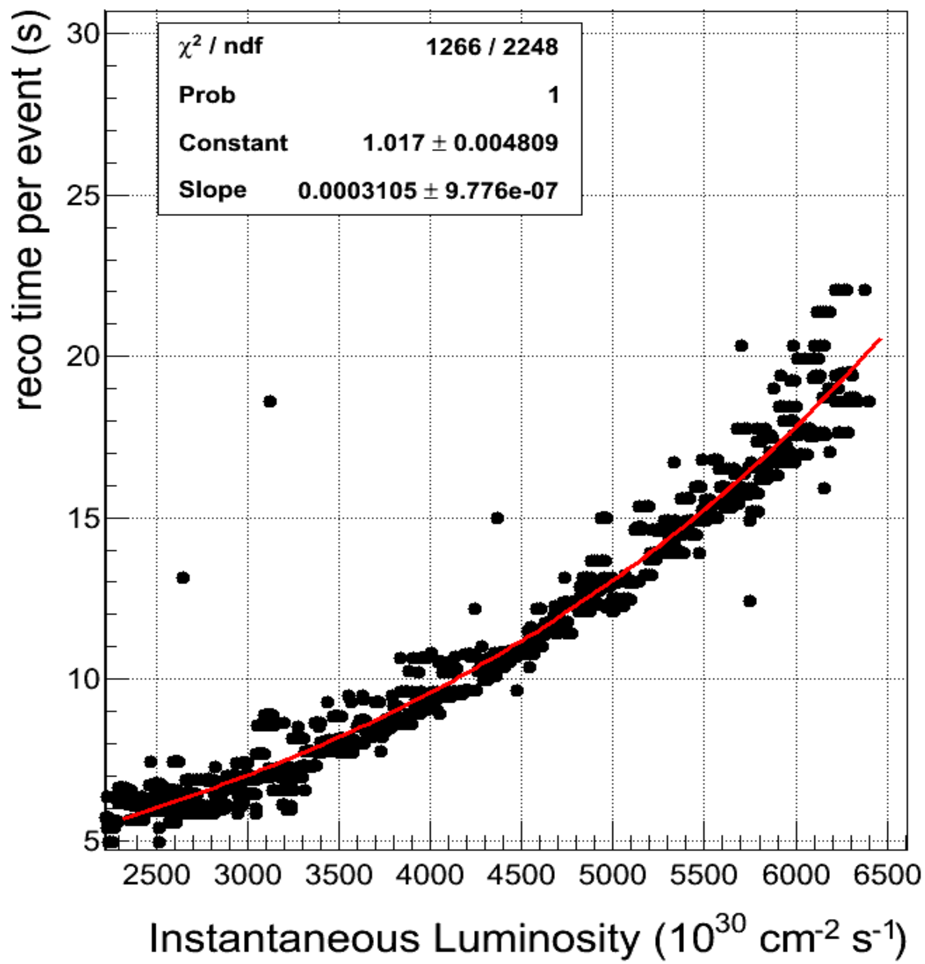
Experimental Goals

- **Physics:** precision measurements at the EWK scale while searching for new particles at the multi-TeV scale
- **Detector:** extend and enhance detector capability, especially in the endcap region where effects of PU and radiation are most severe
- **Pile-up:** maintain demonstrated robustness with 6x higher pile-up
- **Trigger:** maintain low thresholds for precision Higgs measurements and high purity for broadband particle searches and rare processes
- **Computing:** maintain maximum throughput at maximum efficiency

CMS upgrade plans target the experimental challenges that must be met to achieve these goals

Trigger and DAQ Challenge

- **Trigger @ 2 x 10^{34} and 50 PU**
  - Rate doubles just from $\sqrt{s}$
  - Further increased by in-time and out-of-time pile-up
  - HLT output rate ~2.4kHz with no change to existing system
- **Reconstruction**
  - Need ~10x more cpu power without 10 x €€
    - 2x from new hardware
      - Moore's Law helps
    - 5x from smarter algorithms (similar to gains achieved in 2012)
  - Plan in place

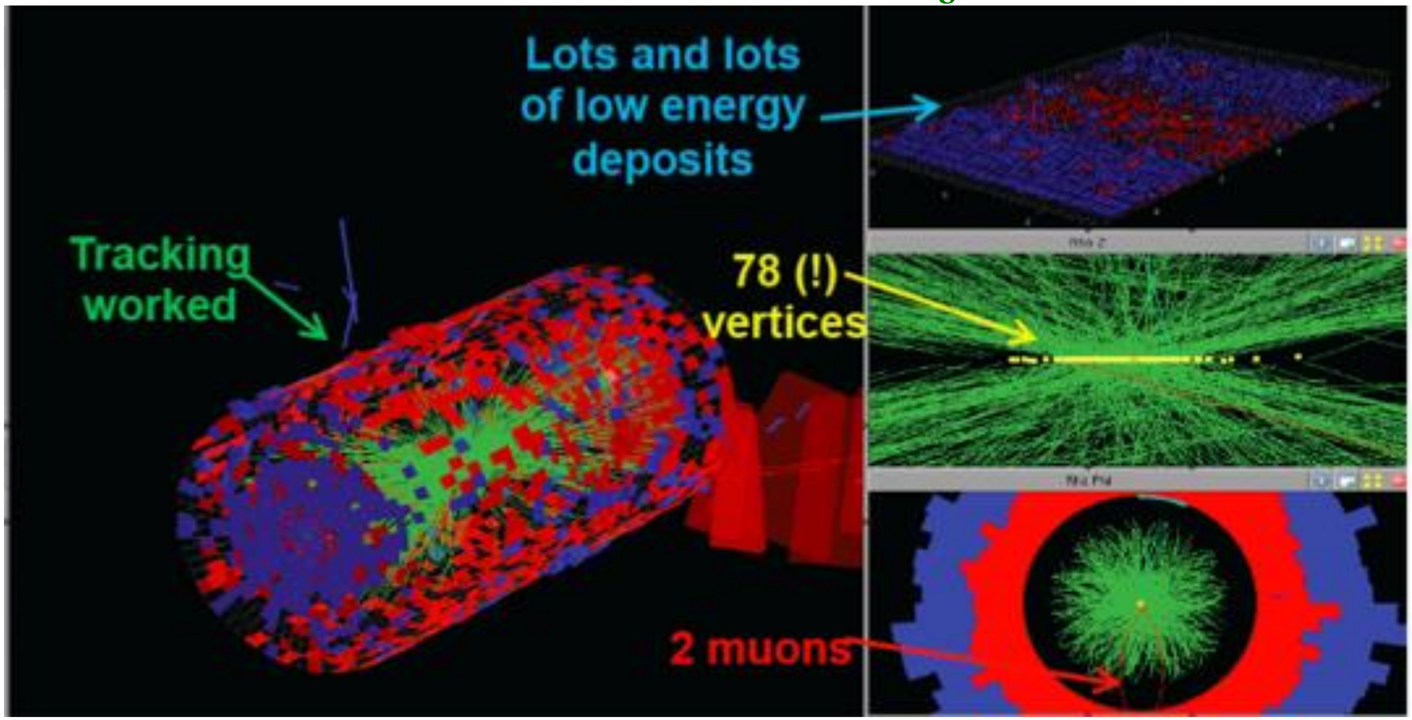


Pile-up Challenge

- **Roadmap to success in 2020 and beyond**
  - Increased detector granularity
  - Increased data bandwidth and cpu power
  - Increased radiation hardness
  - Decreased material budget

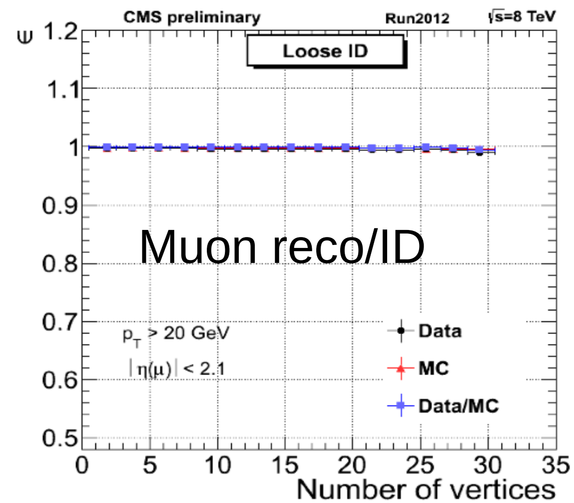
Upgrade plan designed to meet this challenge

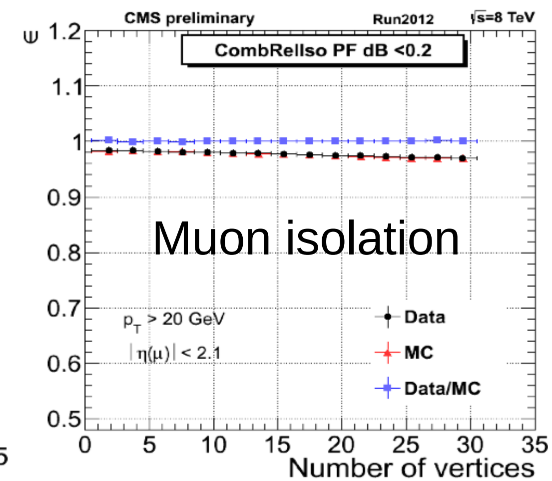
Dedicated high-PU run with 78 vertices

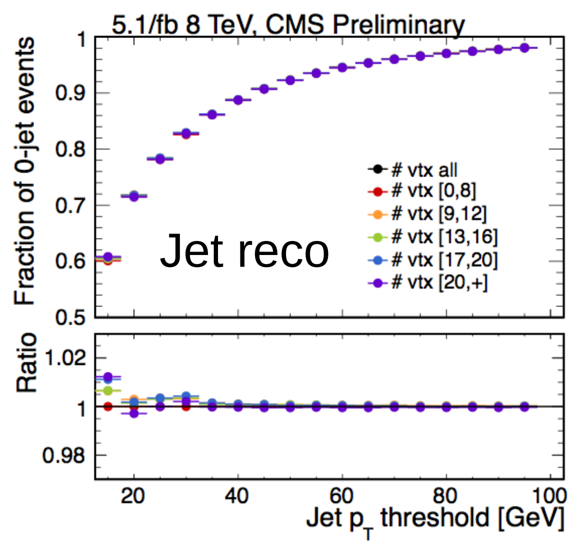


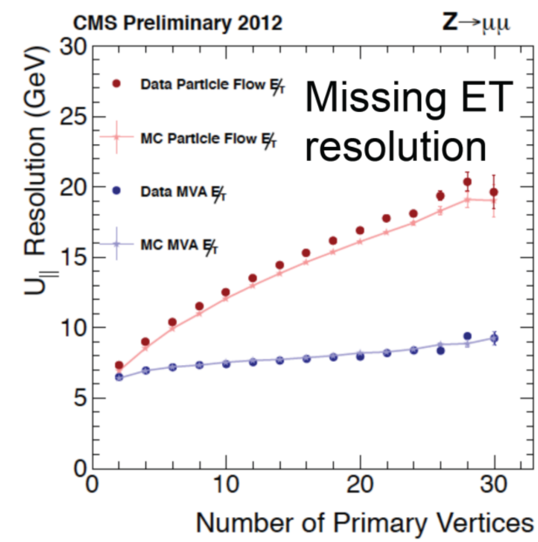
Pile-up (2012): a success story

- **Learning to adapt**
  - Pile-up in 2012 exceeded design specification
  - Mitigation via extensive use of particle flow and advanced analysis methods
    - **Tracker is critical**
- **Key enablers**
  - Detectors with high granularity
  - Intelligent computing/analysis
  - Help from theorists (Fastjet)!





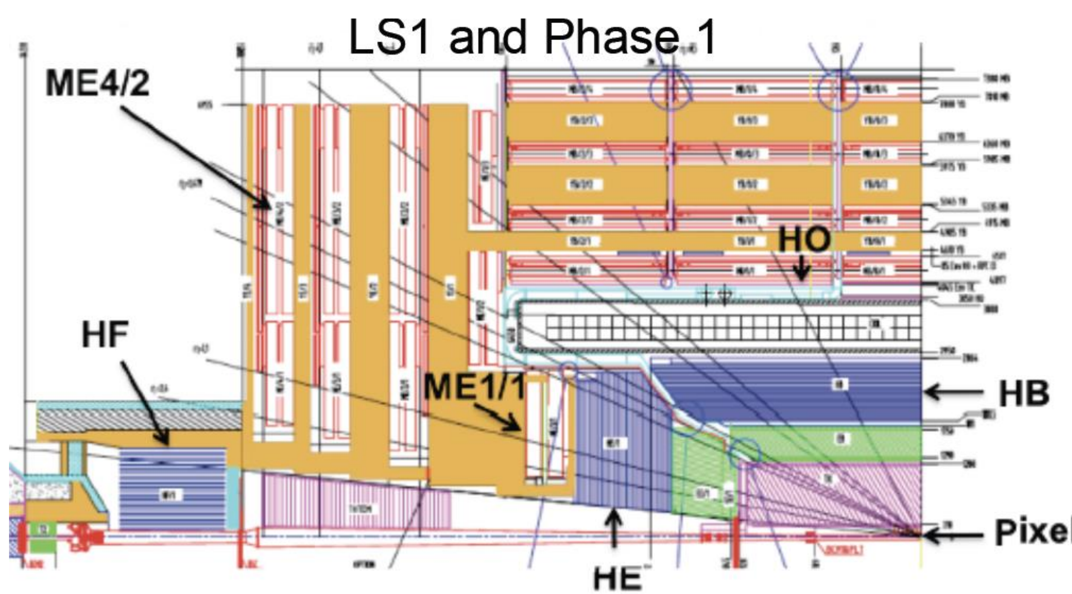




CMS Upgrades

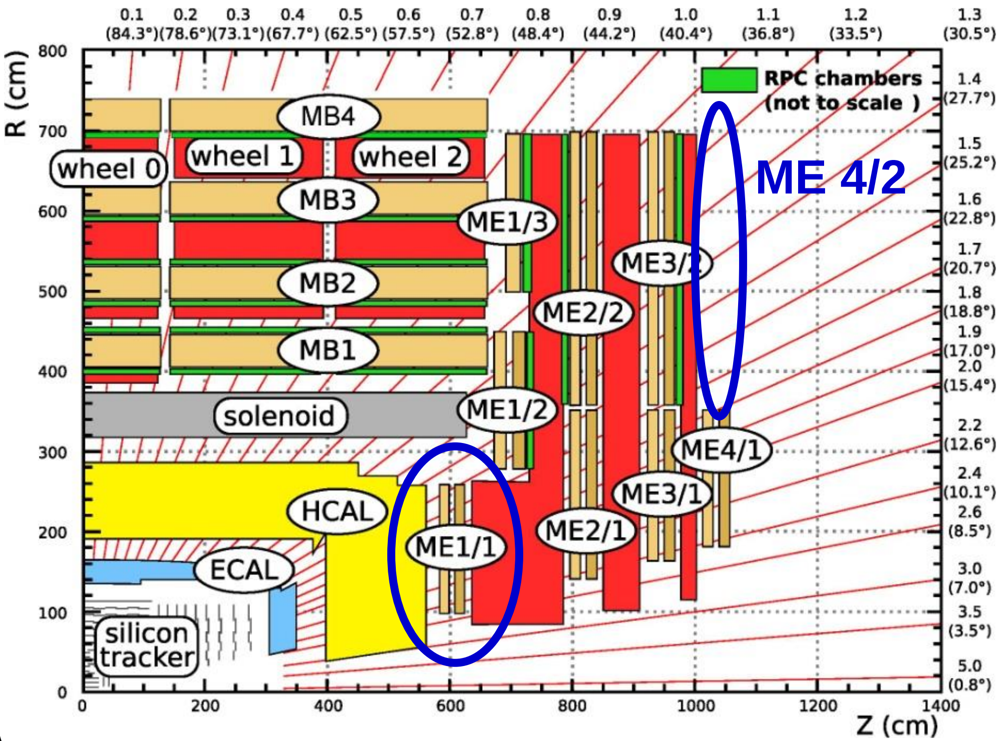
LS1 and Phase 1 Plans

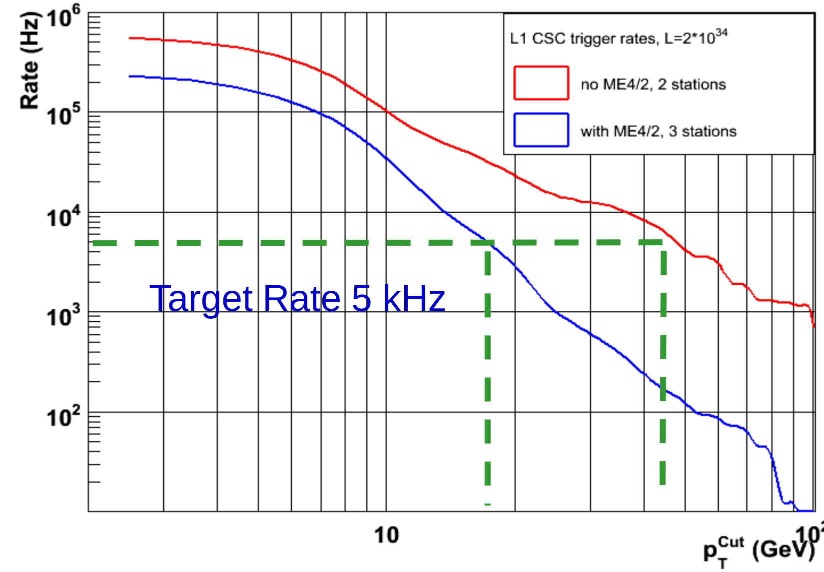
- **LS1 consolidation for $L = 1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$**
  - **Unfinished business**: muon coverage (ME 4/2), colder tracker ops (-20°C)
  - **Lessons learned**: improved muon trigger (ME 1/1) and electronics, replace HCAL photodetectors (thinner PMT windows in HF, SiPMs in HO)
  - **Phase 1 preparation**: new beampipe, infrastructure upgrades
- **Phase 1 upgrades:**
  - **L1 trigger upgrade**
    - Critical for maintaining low trigger thresholds at high lumi
  - **New pixel detector**
    - Tracking, b-tagging and robustness against pile-up
  - **HCAL PDs/electronics**
    - Longitudinal segmentation gives additional pile-up mitigation

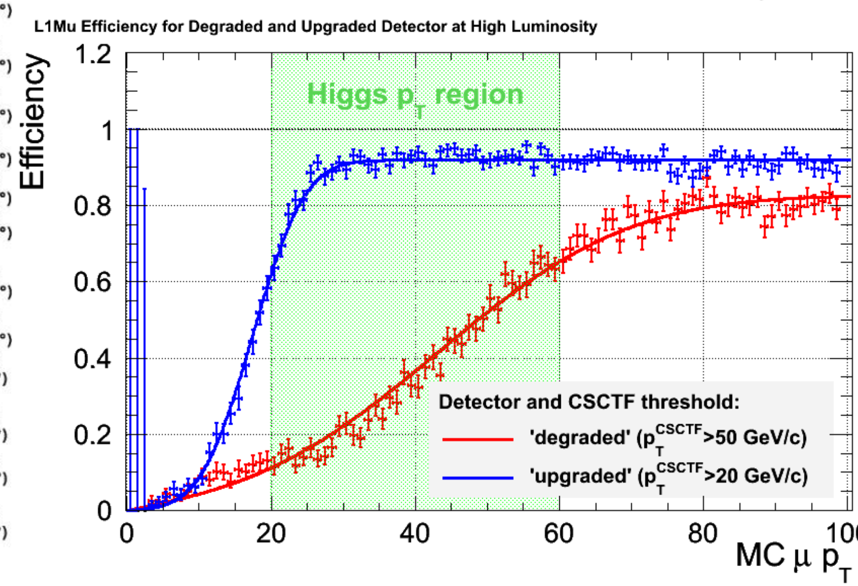


LS1 Muon Upgrade

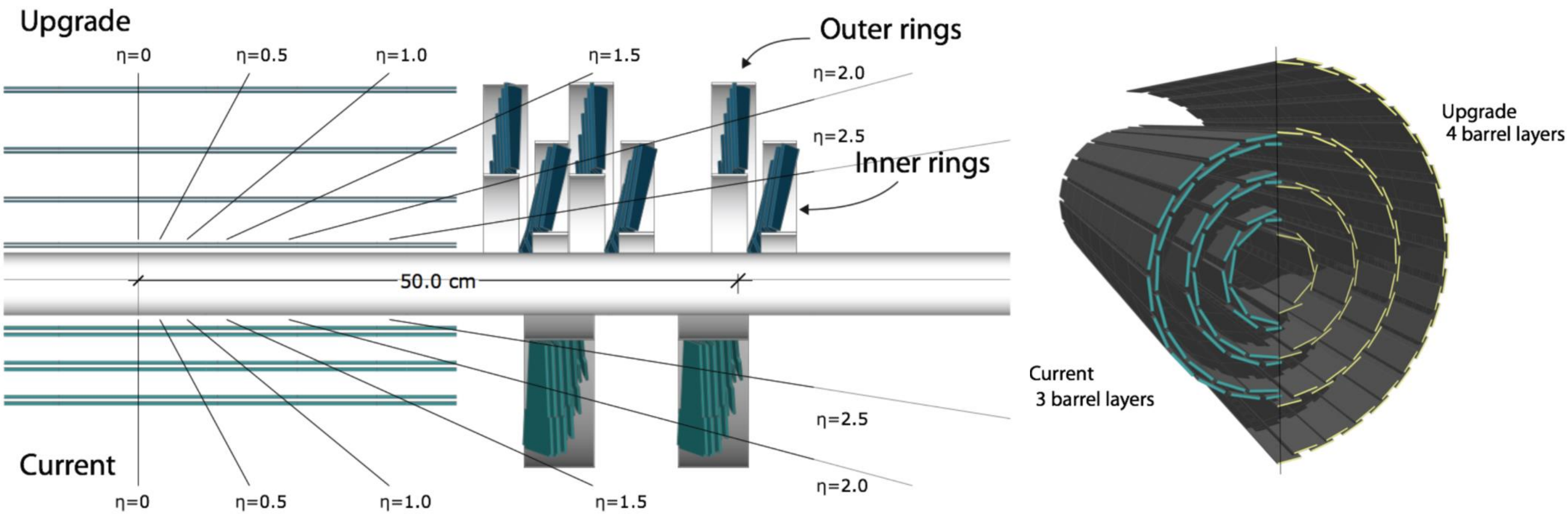
- **Upgrade plans**
  - CSC and RPC: ME4/2 ($1.25<|\eta|<1.8$)
  - CSC: ME1/1 ($2.1<|\eta|<2.4$)
    - new digital boards and trigger cards
  - DT: new trigger readout boards and optical links
- **Improved trigger rate and efficiency**







Pixel Upgrade

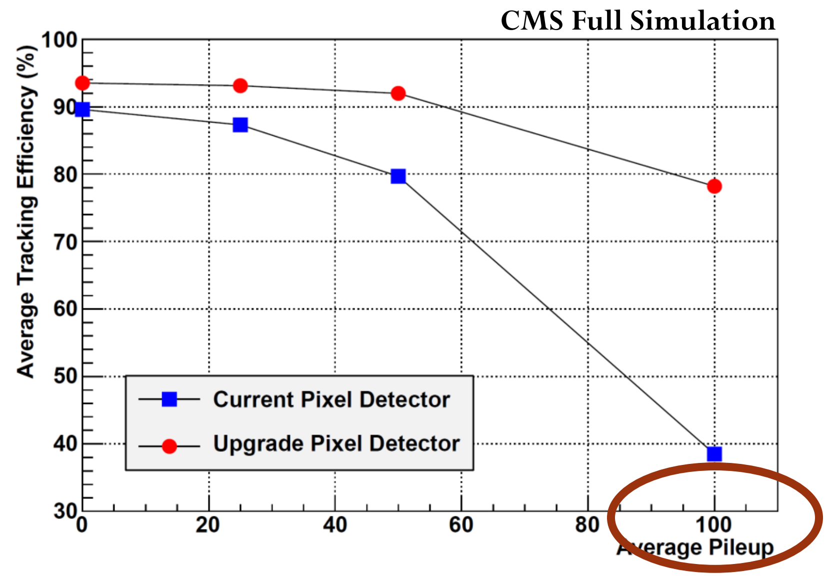


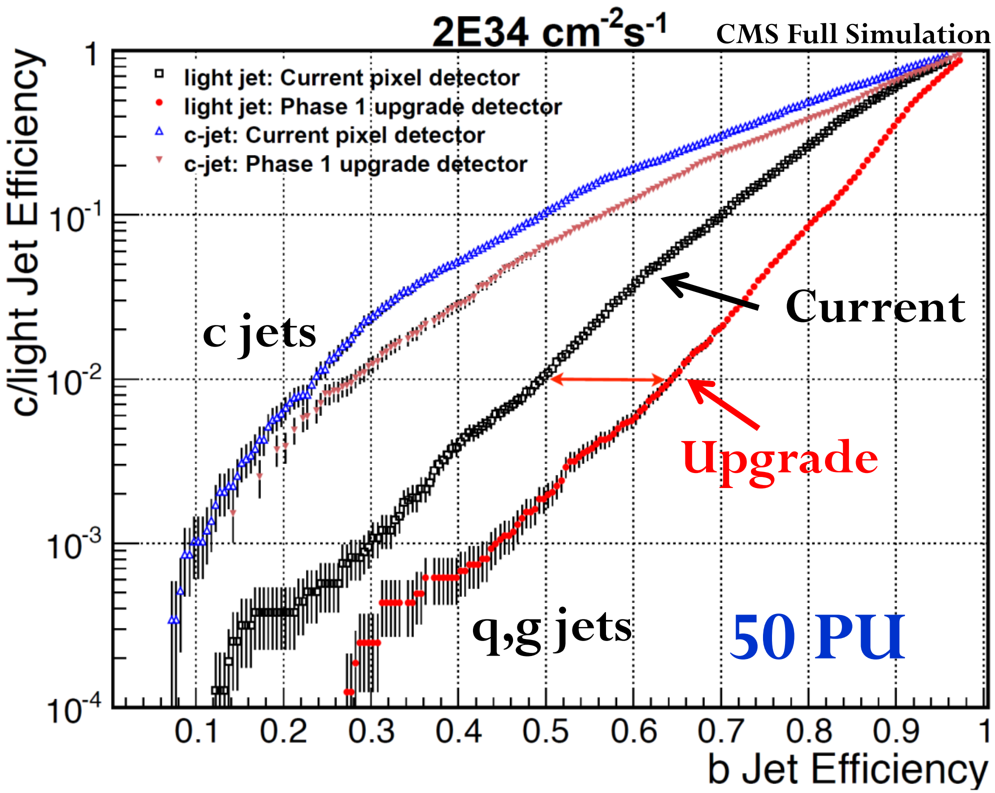
Ready to install by end of 2016

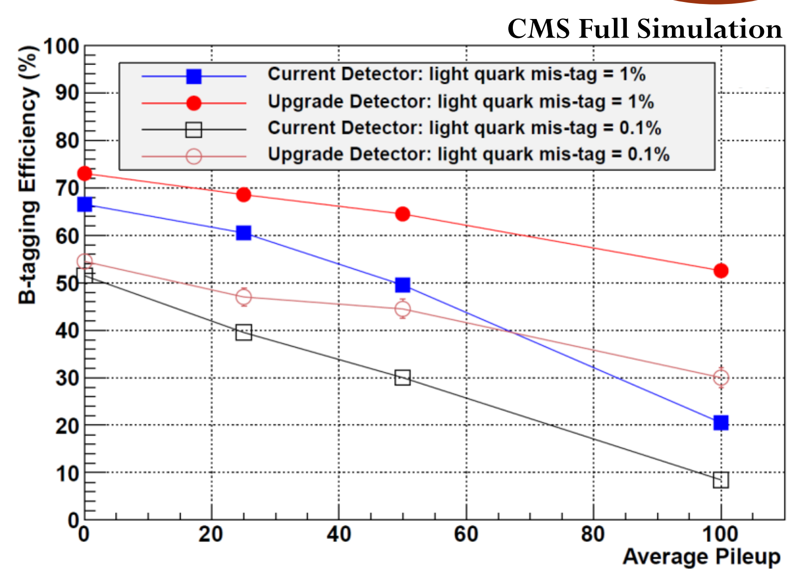
- **Features**
  - Increase barrel layers from 3 to 4, endcap disks from 2 to 3
  - Smaller inner radius (facilitated by new beampipe), larger outer radius
  - New readout chip with increased bandwidth capability
  - Reduced mass and enhanced infrastructure (cooling, cabling, DAQ)

Performance of Pixel Upgrade

- Tracking efficiency stable out to 100 PU
- B-tag efficiency @ 50 PU is better than existing performance at 8 TeV (~20 PU)
- Algorithms not yet optimized for new geometry, ultimate performance might be better

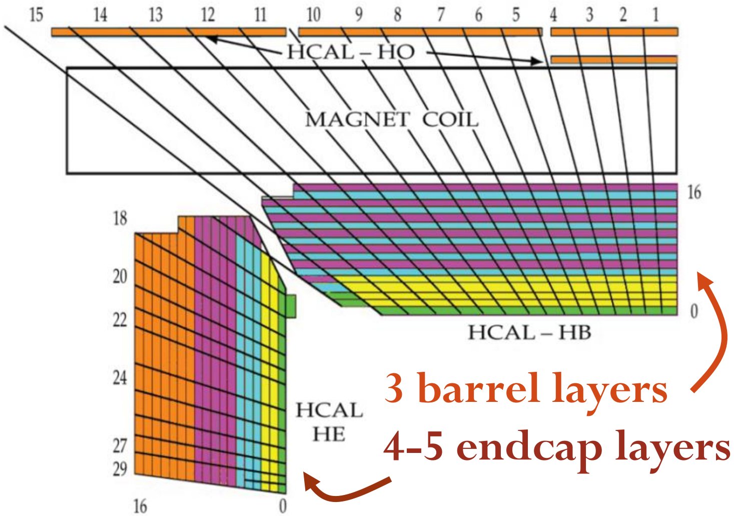




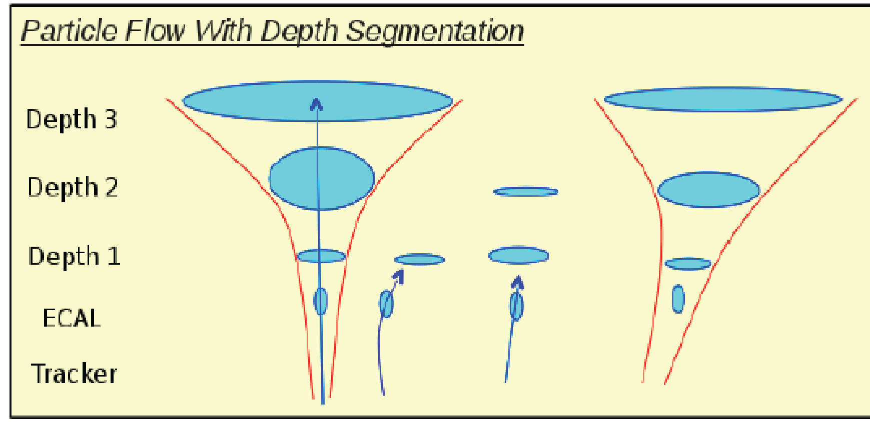


HCAL Upgrade

Colors indicate longitudinal segmentation

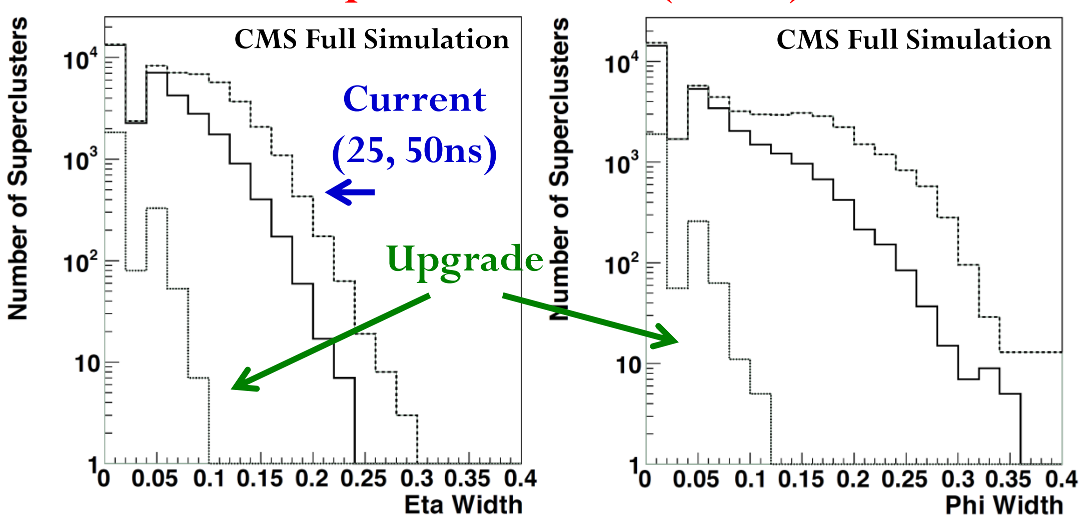


Depth segmentation: exploit shower shape



HF upgrade end of 2015, HB/HE in LS2

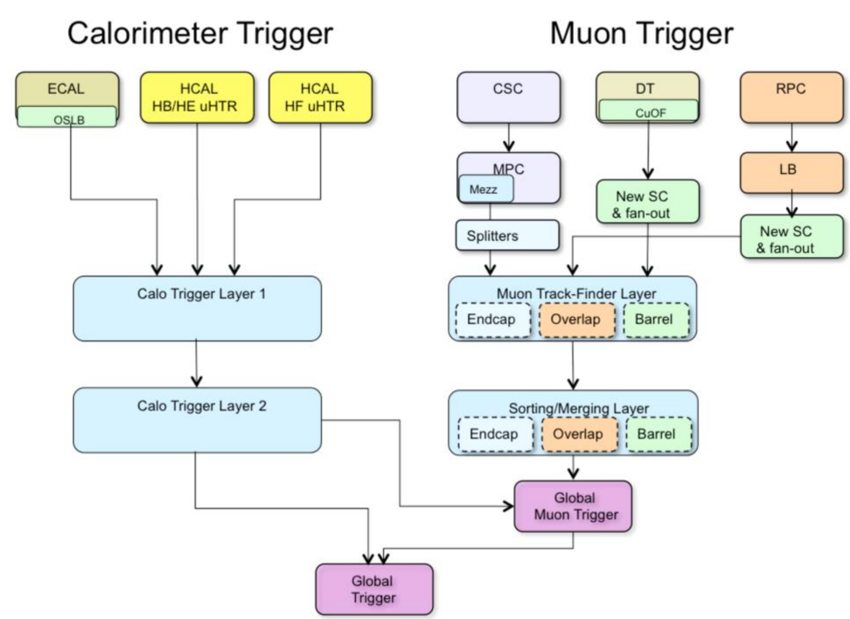
Supercluster Size (50 PU)



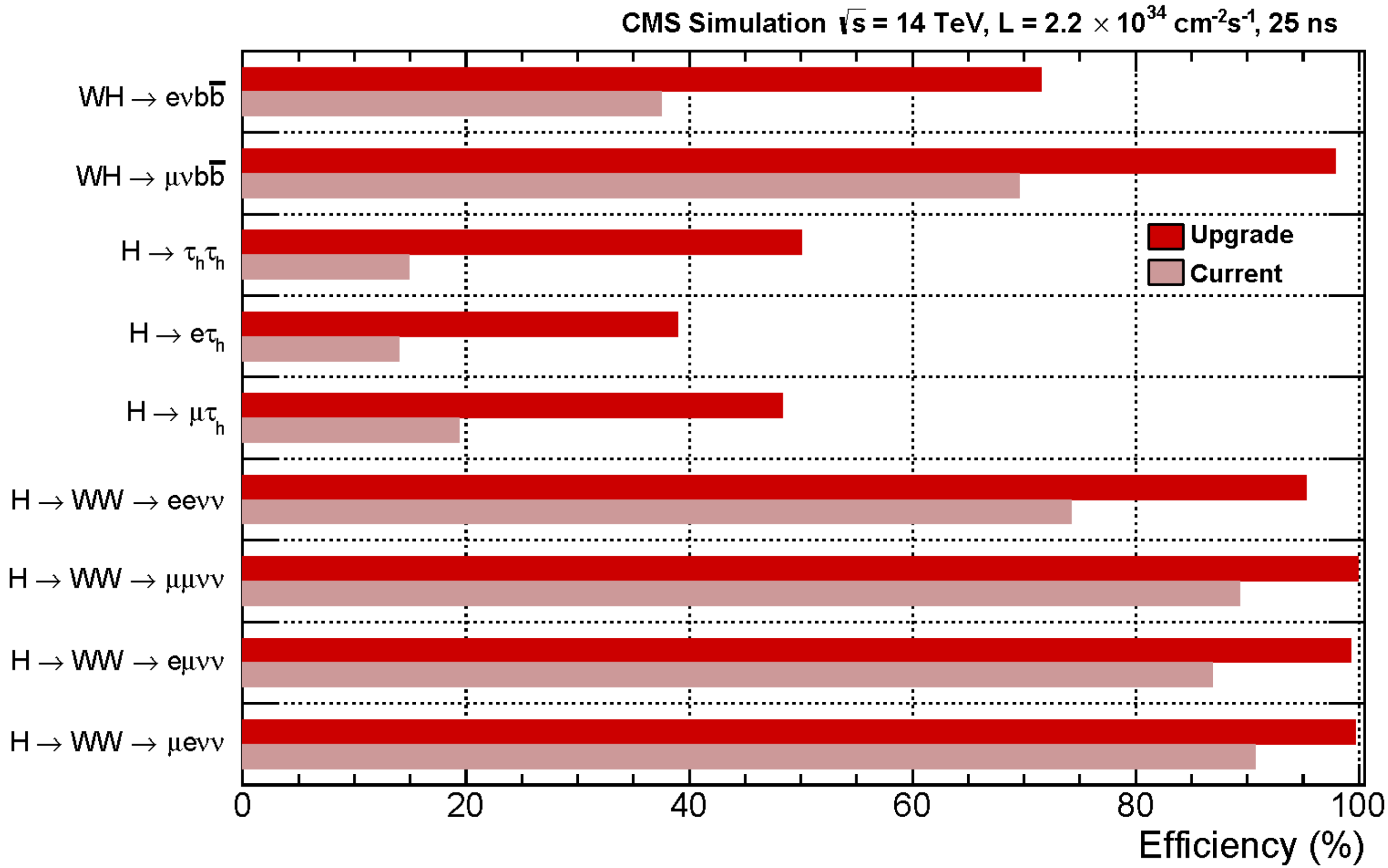
- **Features**
  - New photodetectors (SiPMs)
  - Longitudinal segmentation
- **Enhanced performance**
  - MET resolution
  - Particle flow reconstruction
  - Pile-up mitigation
  - Background rejection

L1 Trigger Upgrade

- **Upgrade plan**
  - Factor of ~6 increase in rate with no change to existing menu
  - Deploy PU subtraction and isolation, improve muon reco, increase flexibility of global L1 trigger (expanded menu)
- **Features**
  - High bandwidth optical links
  - FPGAs with extensive memory
  - In-situ commissioning in parallel with existing system
  - Available for data taking in 2016

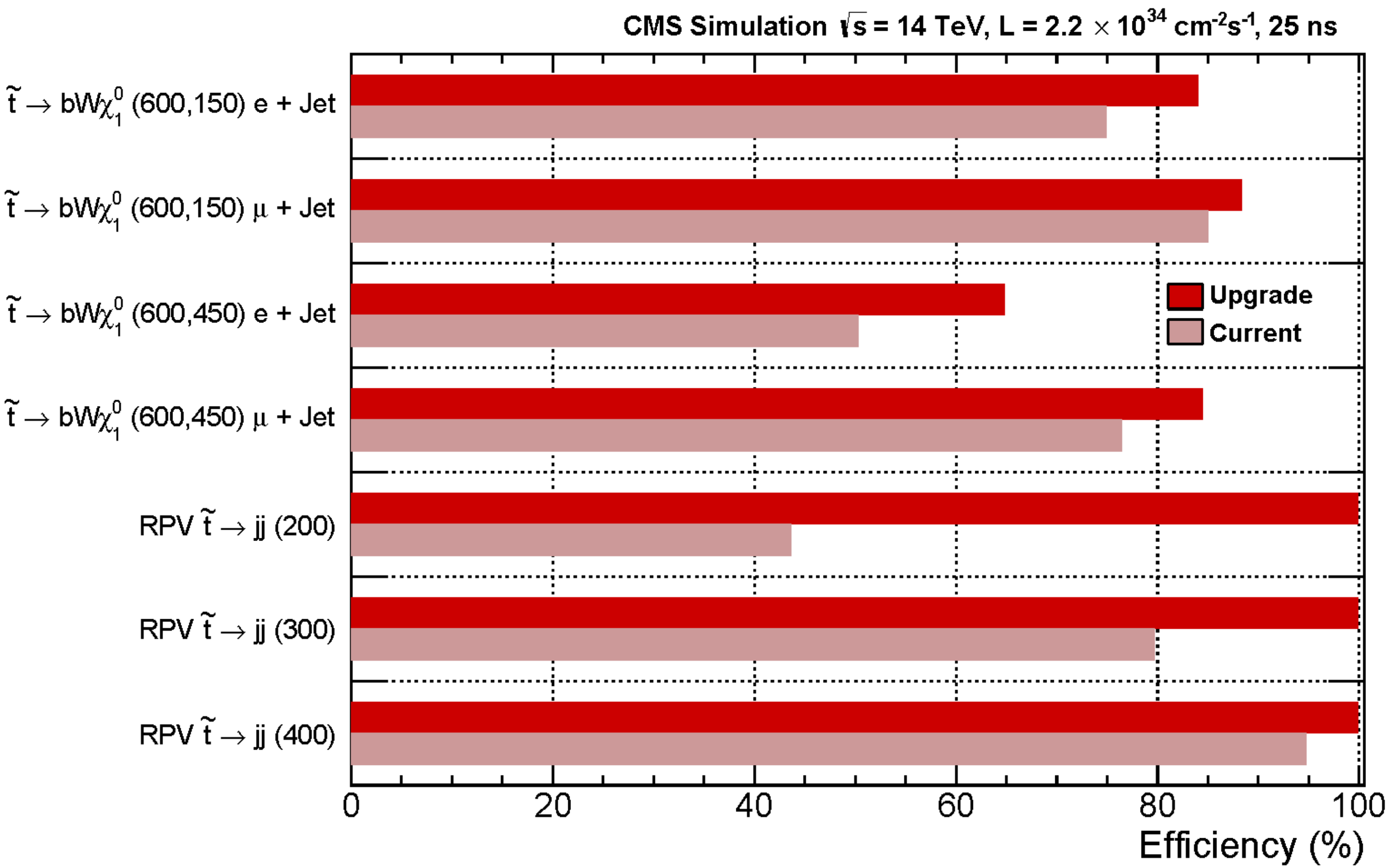


Trigger Upgrade Performance: Higgs



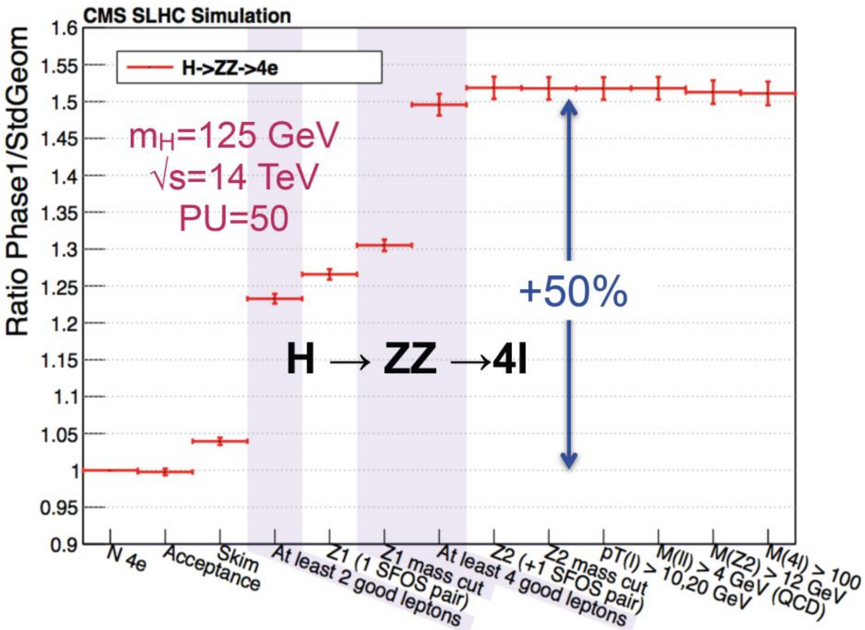
- **Significant efficiency gains in Higgs analyses with leptons:**
  - Efficiencies for WH → eνbb and H → $\tau_e\tau_h$ ~double relative to existing menu run at 50 PU

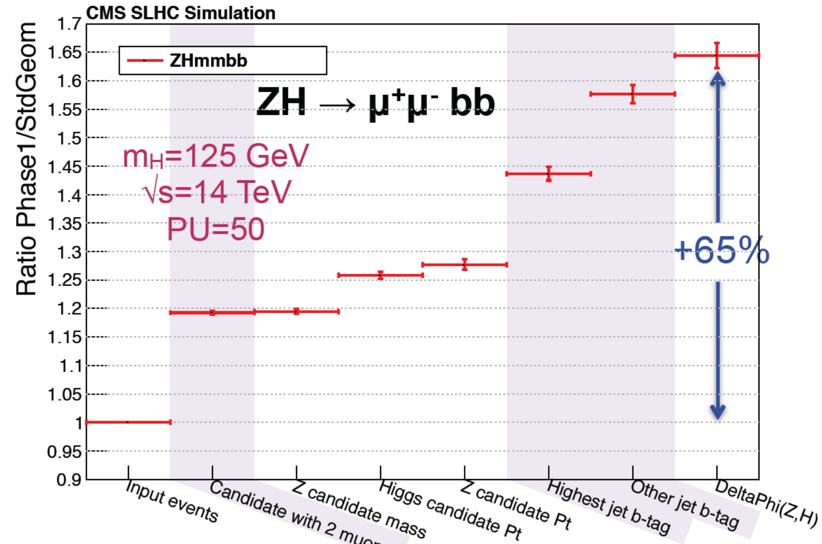
Trigger Upgrade Performance: SUSY



Trigger efficiency for stop searches also improves, especially in RPV scenarios

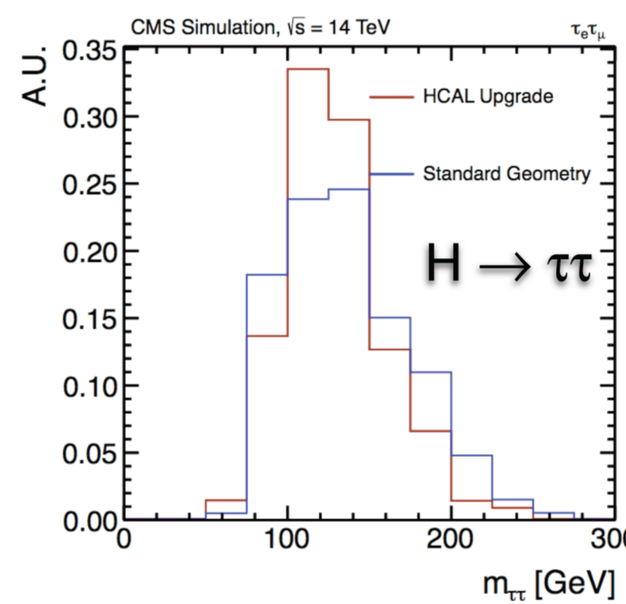
Impact of Upgrades on Higgs Physics





- **CMS Phase 1 upgrade benchmarked against several Higgs analyses based on existing data**

- **Full simulation @ 14TeV and 50 PU demonstrates substantial improvements in key channels**
  - +50% efficiency in ZZ(4ℓ), +65% in ZH(bb)
  - Improved mass resolution in H(ττ)

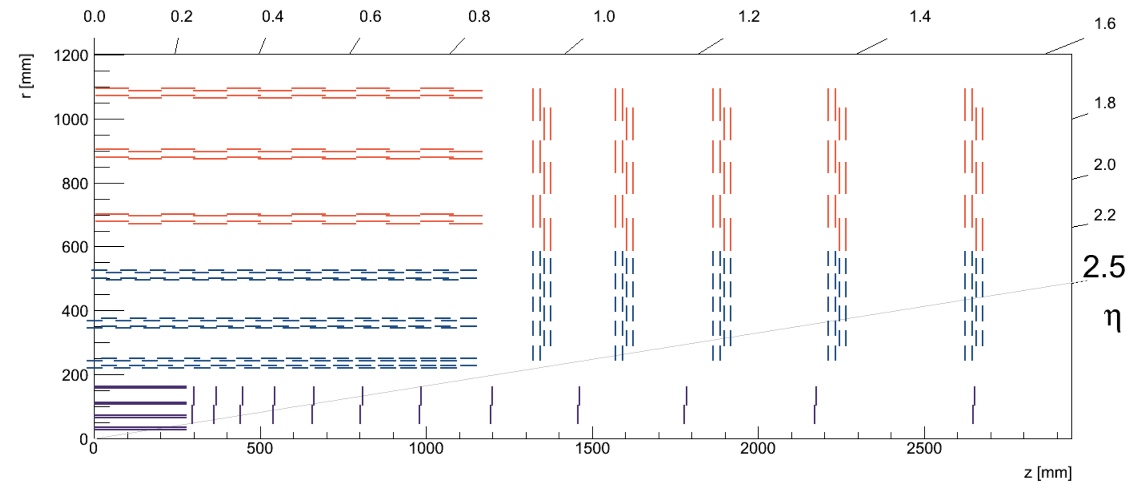


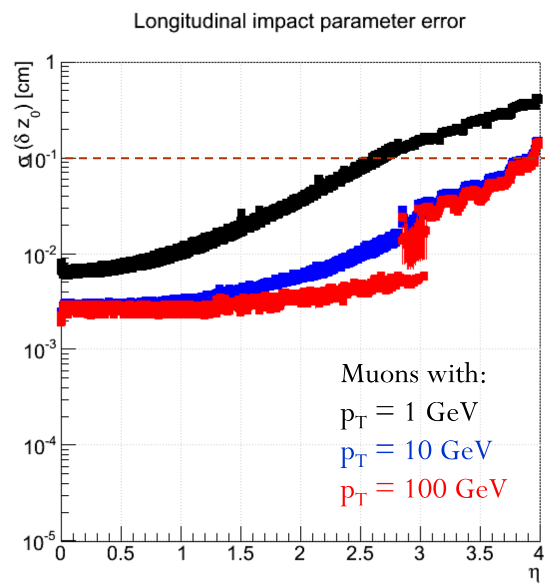
Phase 2 Upgrade Paths

- **HL-LHC environment**
  - Average of 128 interactions per crossing
  - Detector aging from radiation
- **Upgrade goal:** retain and **enhance** detector capability to match or **improve** the performance CMS achieved in Run 1
  - Tracker replacement (providing tracking capability in L1 trigger)
  - Trigger upgrade (options: 1 MHz @ L1, 10kHz @ HLT, track trigger)
  - Replace endcap calorimeters (ECAL+HCAL) due to radiation damage
    - HF seems ok out to $|\eta| \sim 4.5$
  - Shielding and infrastructure: YB0 services, trigger, DAQ, …
  - Additional options under study:
    - Forward pixel tracking ($|\eta| < 4$)
    - Fast calorimeter timing for additional pile-up mitigation
    - Extended muon coverage

Forward Tracking

- **Addition of up to 9 disks extending > 2.5m from IP**
  - Tracking coverage to $|\eta| = 4.0$
  - Pixel-only beyond $|\eta| = 3.2$
- **Potential impact:**
  - Enables μ-track matching, isolation, and extended $\mu/e/\gamma$ coverage
  - Improved particle flow:
    - Pile-up mitigation
    - Improved jet energy resolution
  - Enhanced VBF jet tagging
  - Forward b-tagging





Longitudinal position resolution of ~few mm or better out to $|\eta| = 4$

Work in progress, feasibility under study

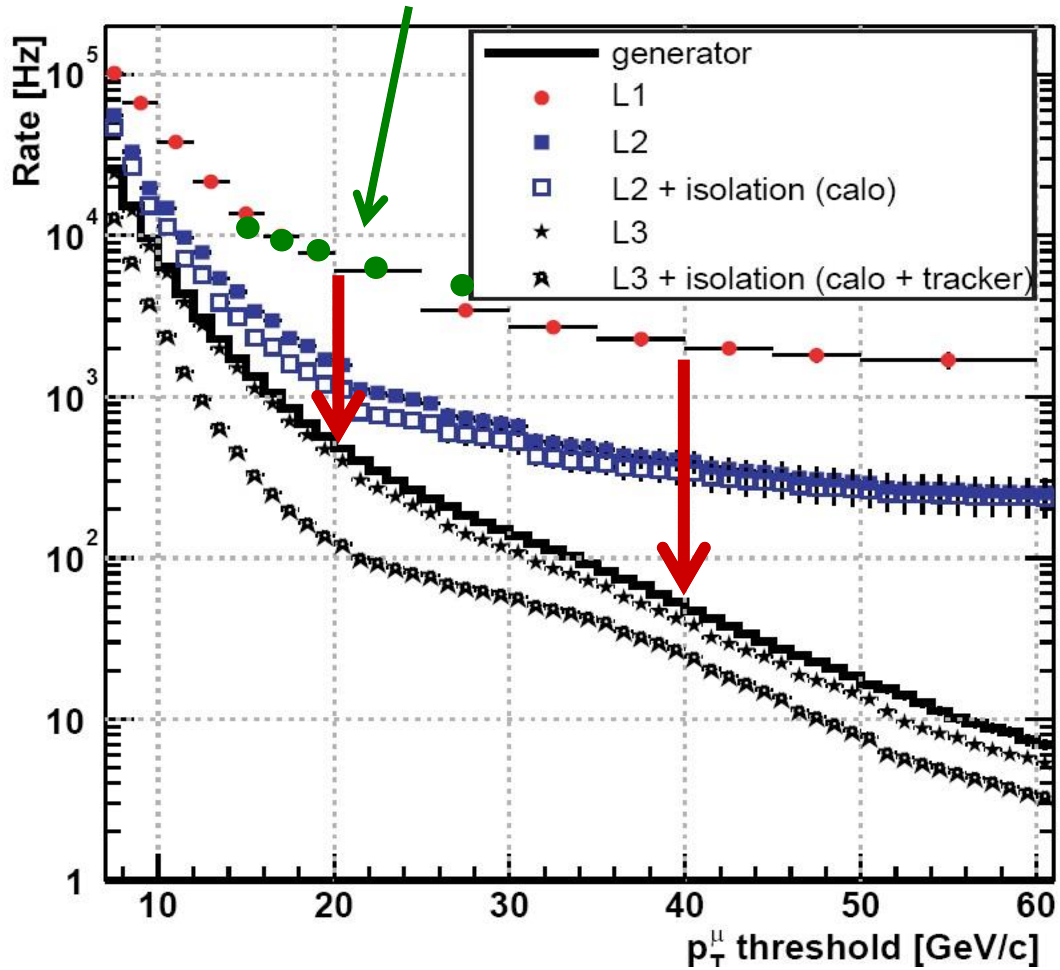
Track Trigger

Enables track matching of muons and electrons (π^0 rejection) and application of isolation at Level 1

Reducing p_T threshold at constant rate

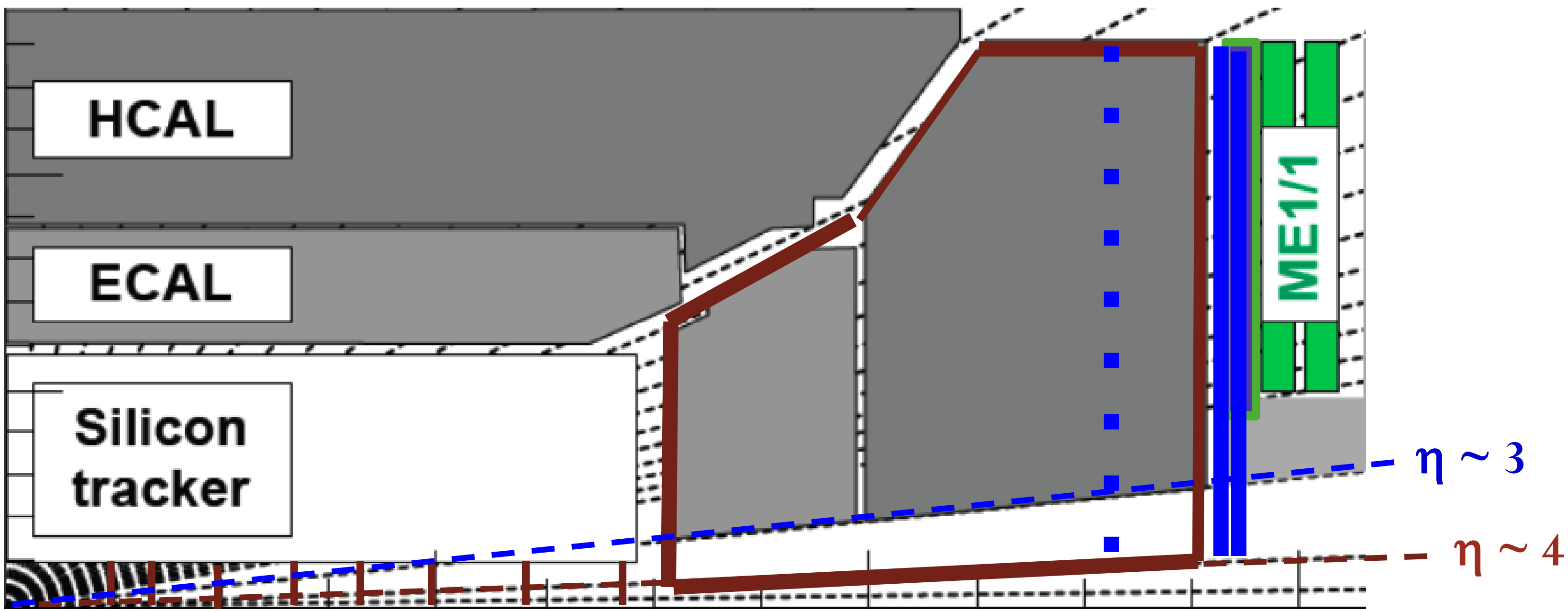
Combined with forward tracking, could provide forward b-tagging at L1

Simulation checked with data at high-PU



Endcap Upgrade Options for Phase 2

- **Under consideration:**
  - Investigate integrated design optimizing particle flow with coverage extended from $\eta = 3$ to 4
  - Replace Endcap calorimeters
    - Range of technologies for EE and HE under study
  - Extend muon coverage to $\eta \sim 4$, possibly including trigger



CMS Physics Potential @ 14 TeV (Higgs and New Particle Searches)

Reminder: ESPG Report (2012)

- European Strategy Preparatory Group (ESPG)
  - Updated proposal for the European strategy for particle physics
  - CMS submitted a document summarizing potential physics reach at LHC14 and HL-LHC (and in some cases, HE-LHC)
    - http://cds.cern.ch/record/1494600?ln=en
- For Snowmass, CMS is updating and extending our ESPG studies

Documentation on CMS upgrades and physics projections can be found at this public twiki:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFP

CMS Public Projected Physics Results

CMS Upgrade and Future Physics Documents

Study	CDS Entry	Projected Luminosity	TWiki with Approved Plots and Additional Information
CMS Submission to European Strategy Group	CMS-NOTE-2012-006	Up to 3000/fb	Higgs ESG
L1 Trigger Phase I Upgrade TDR	CERN-LHCC-2013-011	Up to 300/fb	Summary Plots
HCAL Phase I Upgrade TDR	CERN-LHCC-2012-015	Up to 300/fb	
Pixel Phase I Upgrade TDR	CERN-LHCC-2012-016	Up to 300/fb	
Phase I Upgrade Technical Proposal	CERN-LHCC-2011-006	Up to 300/fb	

Available on CMS information server

CMS NOTE -2012/006

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

24 October 2012 (v2, 18 November 2012)

CMS at the High-Energy Frontier
Contribution to the Update of the European Strategy for Particle Physics

The CMS Collaboration

Abstract

We present a study of the physics potential of the upgraded CMS detector in Higgs physics, searches for new physics, top, and electroweak physics in three scenarios: the LHC (300 fb^{-1} at 14 TeV), HL–LHC (3000 fb^{-1} at 14 TeV), and HE–LHC (300 fb^{-1} at 33 TeV). We also discuss the potential to reduce the PDF uncertainties, which at the moment the limiting systematics for many of these studies. This document has been submitted to the European Strategy Planning Group.

General Comments

- **CMS upgrade strategy:**
  - Define physics motivation, identify challenges, and develop an upgrade plan targeting **improved** performance relative to Run 1
  - Project **existing data** results into the future using conservative vs. optimistic assumptions that **bracket** our future potential
  - Supplement with dedicated studies of important channels using full and parameterized simulation (Delphes)
- **Focus on new projections in this talk:**

  - Updated Higgs coupling uncertainty projections
  - Updated/new estimates of SUSY discovery potential
  - Updated/new estimates of discovery potential for heavy resonances

All new projections are preliminary, to be finalized in white paper

Higgs Projections: Overview

- **Reminder: definition of scenarios**
  - Analyses assumed to be unchanged in the future (pessimistic)
  - Scenario 1 – constant systematic uncertainties (exp and thy)
  - Scenario 2 – scale experimental unc. by $1/\sqrt{L}$, theory unc. by $1/2$
    - Logic: upgrades mitigate pile-up, σ_{exp} mostly data-driven, theorists get smarter
  - **Scenario 2 is our target!**
    - Theory progress is critical to realizing %-level uncertainties on Higgs couplings
- **Updated since ESPG report**
  - Use latest public results for all inputs
    - Added ttH(bb and $\gamma\gamma$), other channels to come by Minneapolis
  - Differences in uncertainty projections come from changes to individual analyses since July, 2012

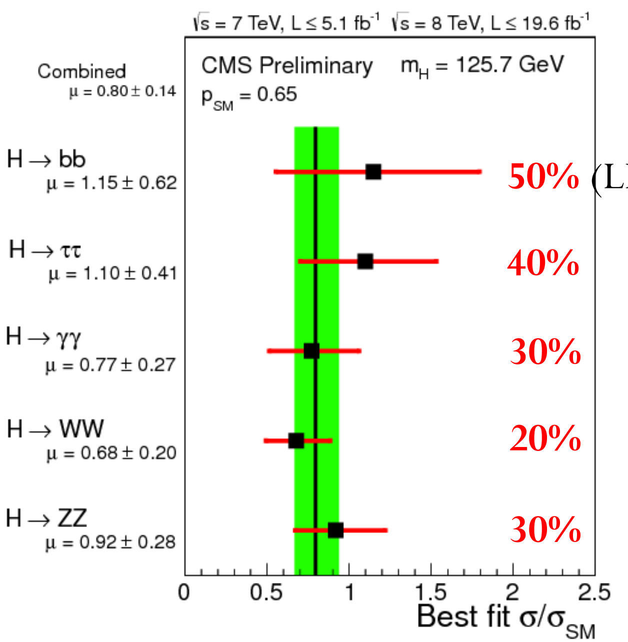
⇒ More details in Higgs session on Tuesday (M. de Gruttola)

Higgs: current measurements

	Significance (m_H = 125.7 GeV)		
Combination	**Expected (pre-fit)**	**Expected (post-fit)**	**Observed**
H→ZZ	7.1	7.1	6.7
H→γγ	4.2	3.9	3.2
H→WW	5.6	5.3	3.9
H→bb	2.1	2.2	2.0
H→ττ	2.7	2.6	2.8
H→ττ and H→bb	3.5	3.4	3.4

Updated @ LHCP (2.1σ)

> 3σ evidence for fermionic decays



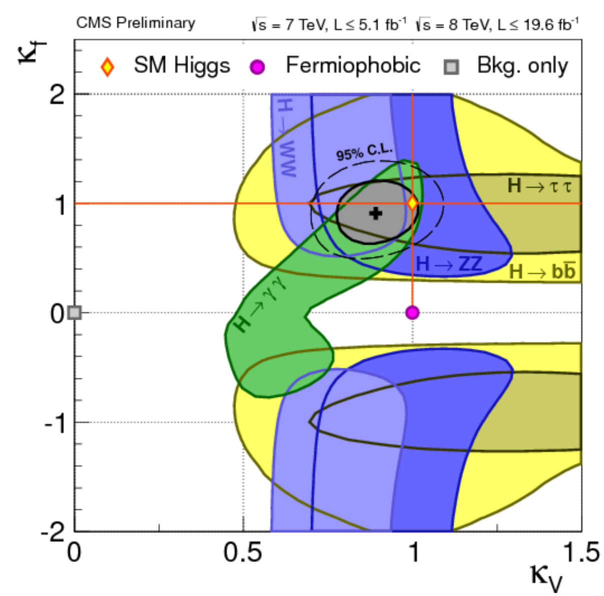
50% (LHCP)

40%

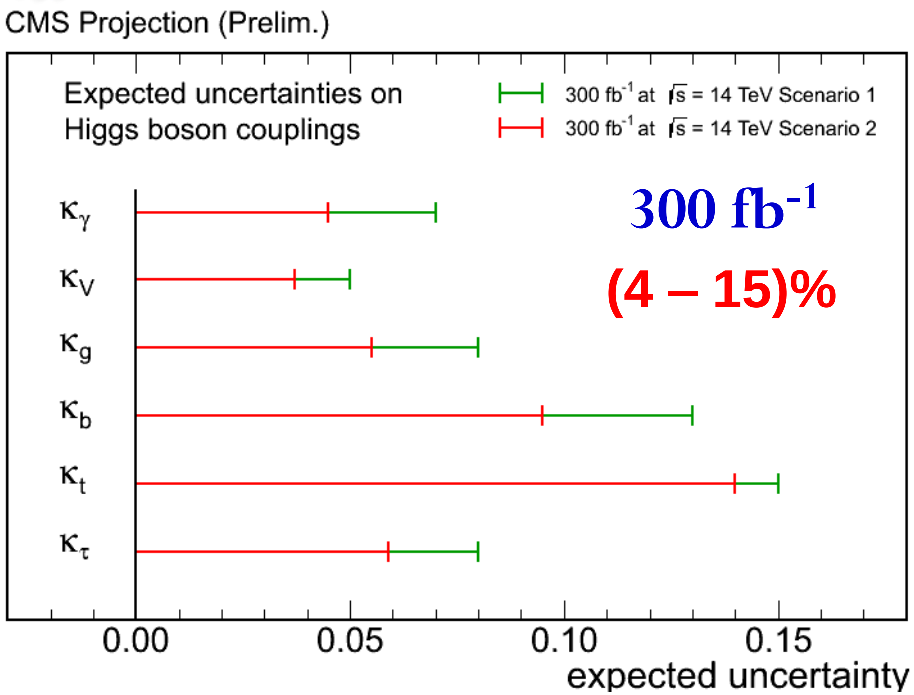
30%

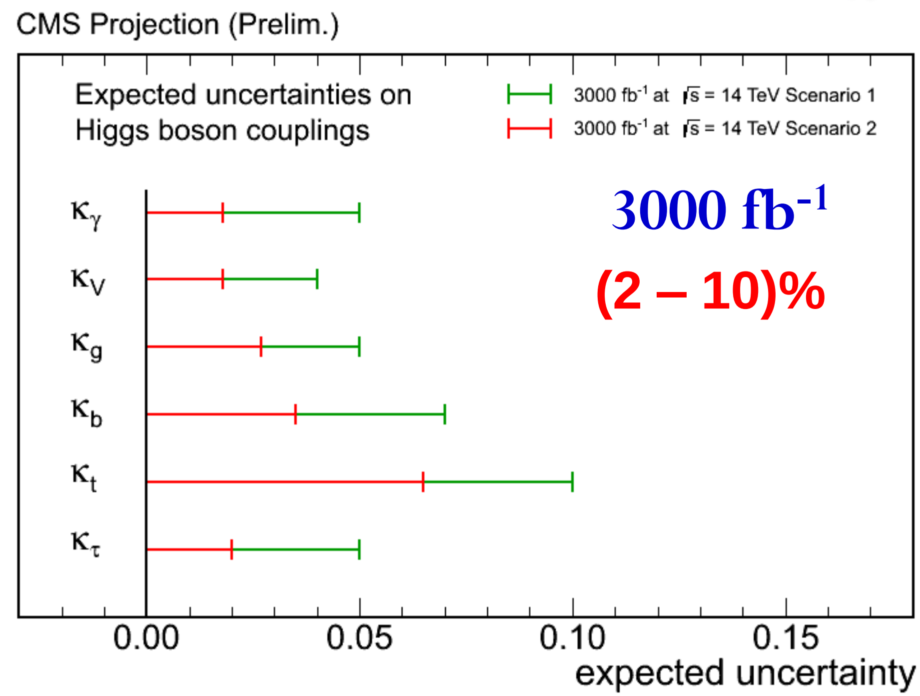
20%

30%



Higgs Projections: 300(0) fb^{-1}





Numbers in brackets are % uncertainties on coupling deviations for [scenario 2, scenario 1]

L (fb^{-1})	κ_γ	κ_V	κ_g	κ_b	κ_t	κ_τ
300	[5, 7]	[4, 5]	[6, 8]	[10, 13]	[14, 15]	[6, 8]
3000	[2, 5]	[2, 3]	[3, 5]	[4, 7]	[7, 10]	[2, 5]

Goal: ultimate precision of ~5% or better

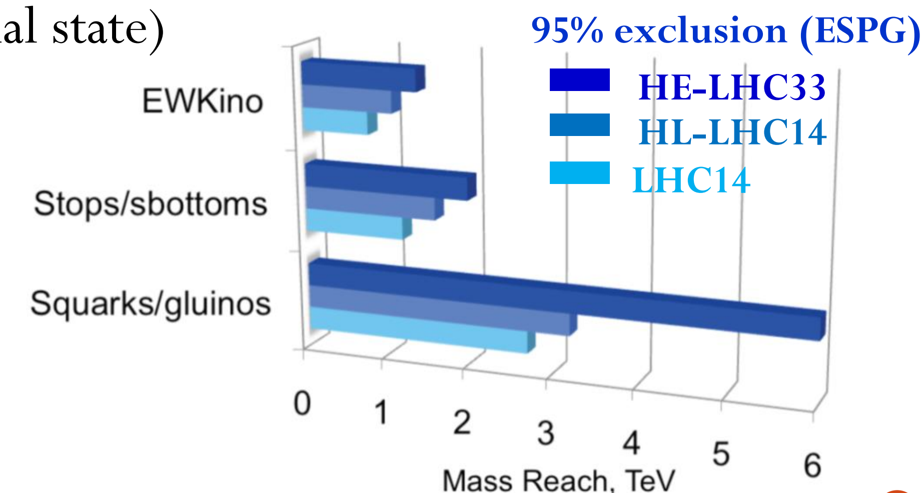
Upgrade Strategy: impact on Higgs

Channel	Key Features	Upgrades addressing future challenge:
$H \rightarrow \gamma\gamma$	di-photon mass	Tracker, trigger, endcap calo, precision timing
$H \rightarrow ZZ$	Lepton reco/iso	Tracker, trigger, muon, endcap calo
$H \rightarrow WW$	Lepton reco/iso, MET	Tracker, trigger, muon, HCAL, endcap calo
$H \rightarrow \tau\tau$	di-tau mass, VBF tag	Tracker, trigger, HCAL, endcap calo, precision timing
$H \rightarrow bb$	b-tagging, di-jet mass	Tracker, trigger, HCAL

Upgrades will specifically address dominant systematic uncertainties impacting Higgs precision measurements and searches for additional Higgs bosons

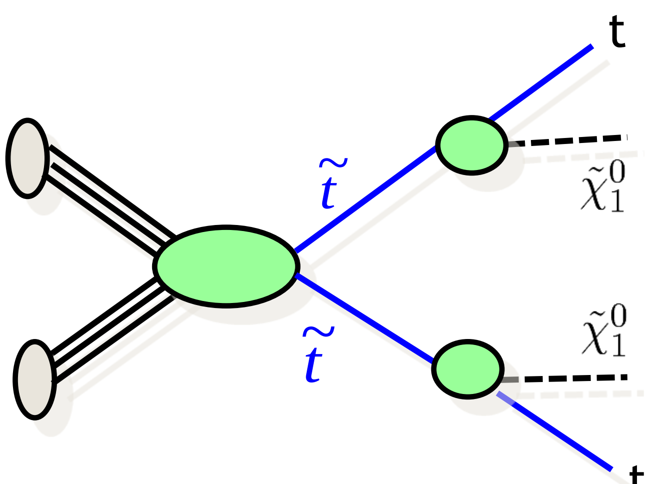
New Particle Discovery Potential

- **Currently simple scaling based on existing public results**
  - Update ESPG estimates using latest public results, quoting 5σ discovery
    - Analyses are assumed unchanged, results are rough estimates of expected reach
  - Work in progress for 3000fb^{-1}: more detailed studies with reoptimized background rejection
- **SUSY benchmarks: motivated by "naturalness"**
  - T2tt: direct stop production ($\tilde{t} \rightarrow t + \mathrm{LSP}$)
  - T1tttt: gluino pair-production ($\tilde{g} \rightarrow t\bar{t} + \mathrm{LSP}$)
  - T6ttww: direct sbottom production ($\tilde{b} \rightarrow t$+W+LSP)
  - TChiWZ: EWK-ino (WZ+MET final state)
- **Exotica:**
  - $Z' \rightarrow ll\ (l = e, \mu)$
  - $W' \rightarrow e\nu$
  - Vector-like quarks

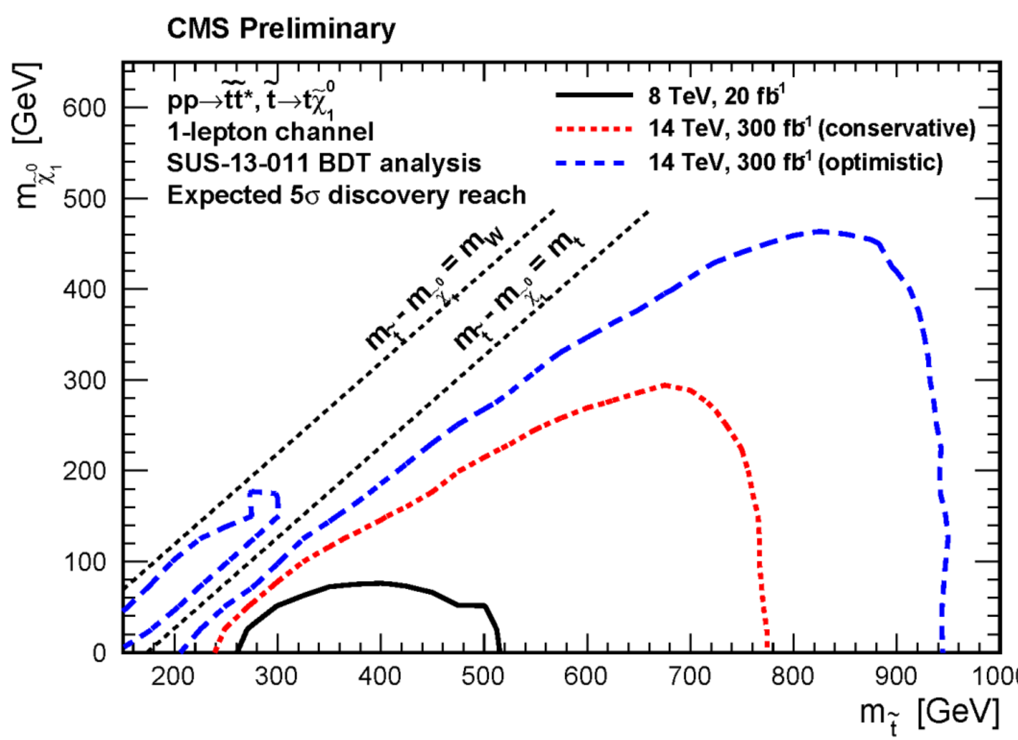


Discovery Potential: Stops

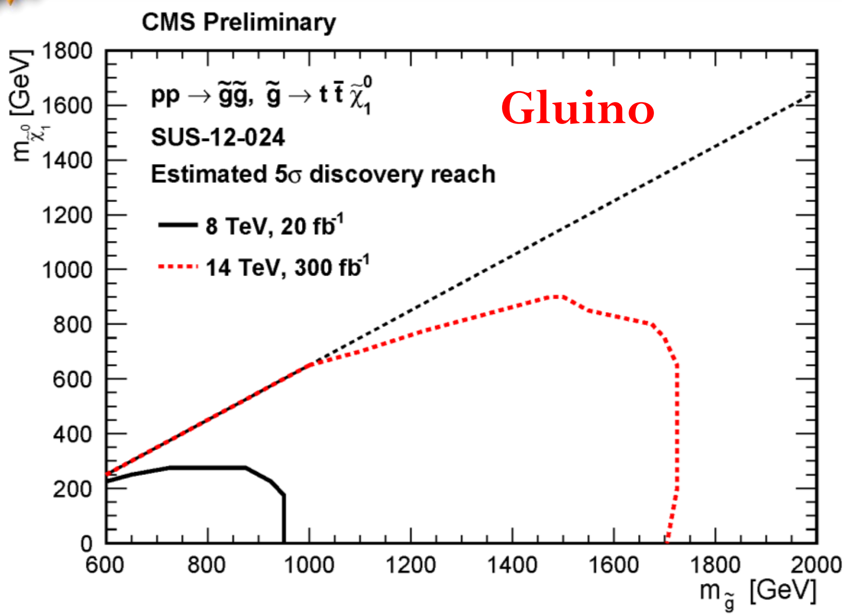
- Two approaches (analysis assumed unchanged)
  - Pessimistic: assume same systematic uncertainties as 8 TeV analysis
  - Optimistic: scale σ_{bkg} like stat. unc., but require σ_{bkg} > 10% relative
- Can discover (5σ) stops up to **750-950 GeV w/300 fb^{-1} (14 TeV)**

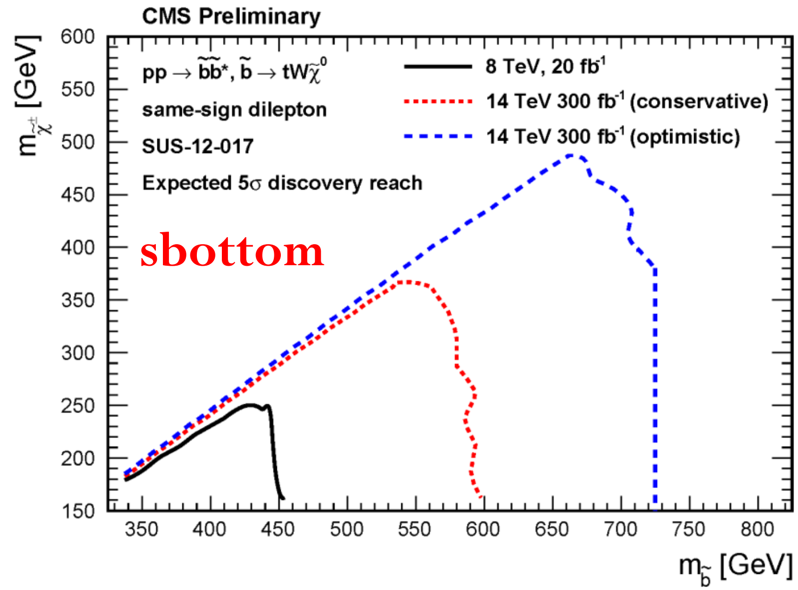


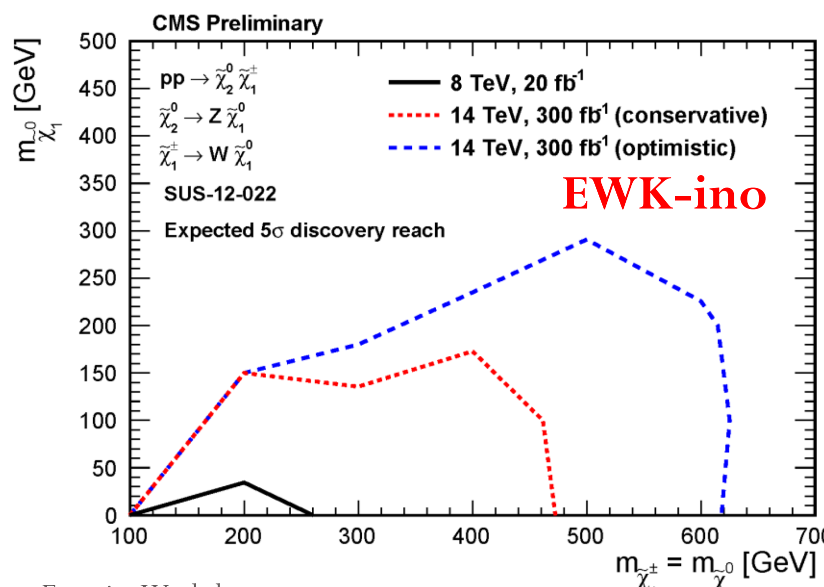
Search in final state with ℓ + jets + MET



Gluinos, Sbottoms, EWKinos



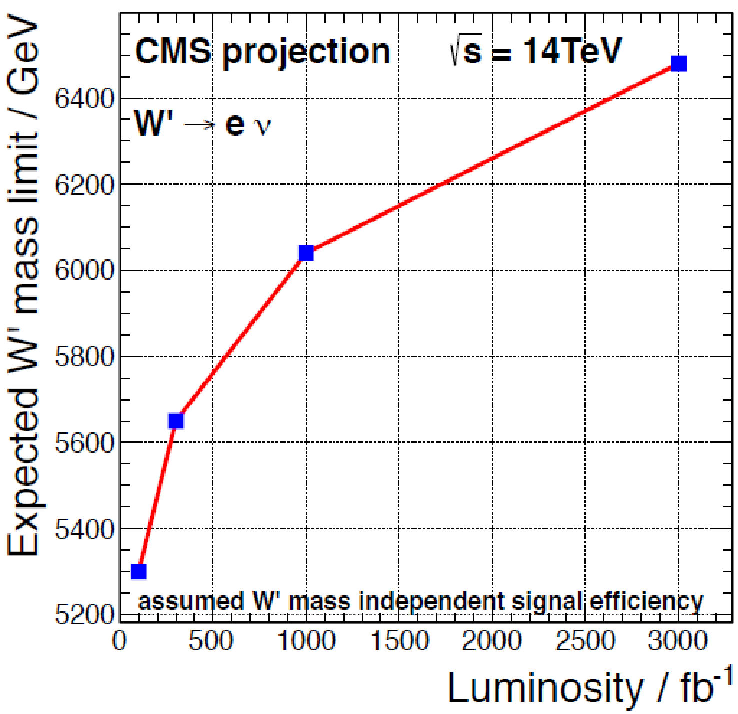


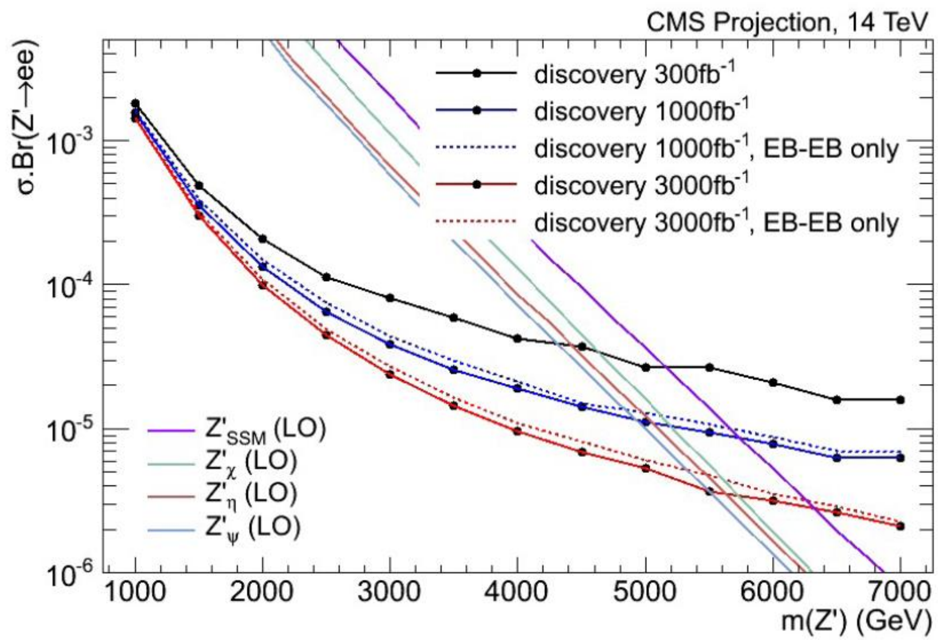


- Two approaches
  - "conservative" and "optimistic" similar to stop scenarios (more details in backup)
  - Analysis methods assumed unchanged
- 5σ discovery reach
  - Guino: up to 1.7 TeV
  - Sbottom: ~600 – 700 GeV
  - EWK-ino: ~500 – 600 GeV

W' and Z' Projections

- $W' \to e\nu$
  - Simple scaling of existing 8 TeV results
  - Assume flat 65% efficiency
- **Exclude up to ~6.5 TeV**



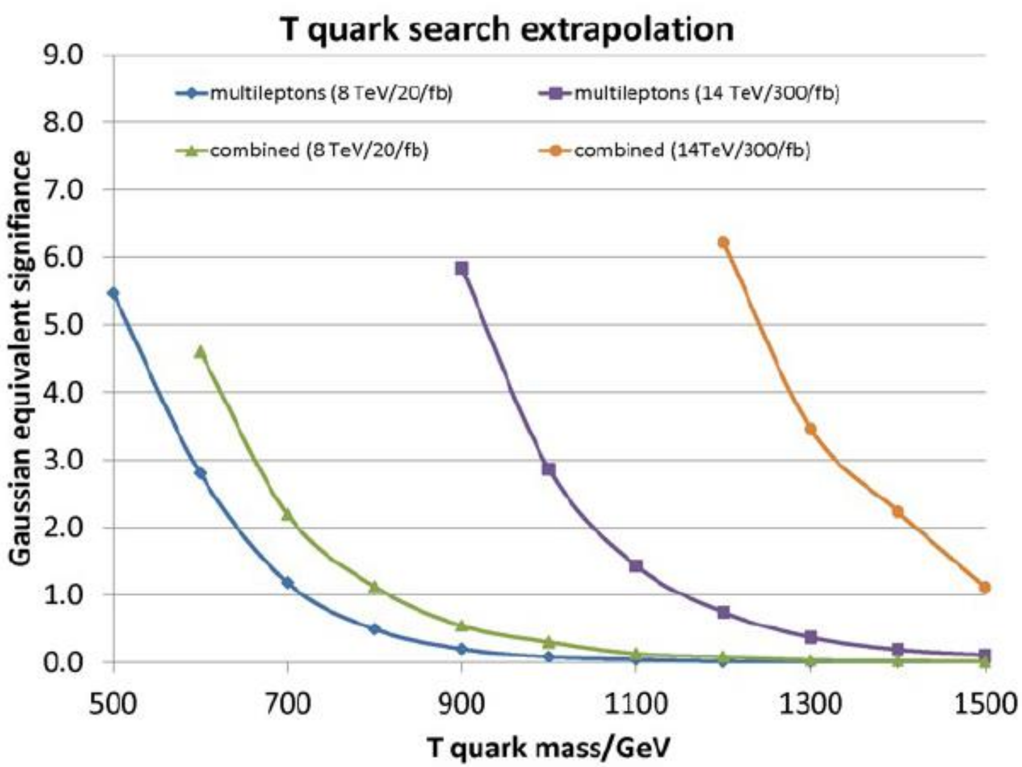


- $Z' \to ll$ generator-level studies
  - Efficiencies from data
  - Electron: E smearing as in 8 TeV, but estimate effect of electron showers saturating in ECAL
  - Muon: smear as in 8 TeV
- **Discovery (5σ) up to ~6 TeV**

T Quarks

- **Massive vector-like top quark**
  - Possible top partner for stabilizing m_H
  - Decays to bW, tZ, and tH
  - Search in events with at least one lepton

Exclude up to 1.5 TeV with 300 fb^{-1}



CMS Plans: Snowmass

- **White paper (end of July)**
  - Finalize Higgs projections
    - Final coupling deviation uncertainties
      - Add inputs from new public results between now and Minneapolis
    - Add projections for spin
  - Finalize new particle discovery projections
  - Summarize physics potential for Top, EWK, and Heavy Ion
  - Simulation studies:
    - Re-optimize SUSY searches @ 3000 fb^{-1} with upgraded CMS detector configuration (either Fastsim or Delphes)
    - Possibly add select Higgs studies for HL-LHC (impact of pile-up mitigation)
- Additional studies could be included before final deadline (Sept)

CMS Plans: Beyond Snowmass

- **Plans for ECFA workshop (October)**
  - ECFA = European Committee for Future Accelerators
  - More time: CMS plans detailed studies using mix of full simulation with high PU, supplemented with additional Fastim and/or Delphes studies
  - Work on Phase 2 upgrade planning will continue beyond ECFA
    - Technical proposal, physics TDR
    - Future outlook continually improving
- **Some examples of studies that drive phase 2 planning:**
  - di-Higgs production ($2\gamma 2b$)
  - VBF: $H \rightarrow \tau\tau$ and EWK-ino search
  - VV scattering at high energy
  - stop pair production
  - Monojets and monoleptons
- **Some of these studies could come in time for the final Snowmass white paper deadline in September**

Summary

- **Discovery of a Higgs boson has focused the future**
  - LHC detectors must remain sensitive to EWK-scale physics
  - While maximizing sensitivity to new particles at the multi-TeV scale
- **LHC upgrades present several challenges**
  - Trigger rate, pile-up, radiation
  - CMS upgrade plans are designed to deal with these challenges head-on
- **CMS Projected Physics Potential (updated)**
  - Uncertainty on Higgs couplings reach ~5% or better
  - SUSY and Exotic discovery potential ranging from 0.6 – 1.7 TeV
- **More to come for Minneapolis (and ECFA)**

Backup Slides

(more details on projections)

Summary of Inputs to Higgs Projections

H decay	Analyses: Prod. tag	Analyses: Exclusive final states	No. of channels	m_H resolution	Lumi (fb^{-1}) 7 TeV	Lumi (fb^{-1}) 8 TeV	Ref.
$\gamma\gamma$	untagged	$\gamma\gamma$ (4 diphoton classes)	4 + 4	1-2%	5.1	19.6	[63]
	VBF-tag	$\gamma\gamma + (jj)_{\mathrm{VBF}}$ (two dijet classes for 8 TeV)	1 + 2	<1.5%	5.1	19.6	
	VH-tag	$\gamma\gamma + (\mathrm{e}, \mu, \mathrm{MET})$	3	<1.5%		19.6	
$\mathrm{ZZ} \to 4\ell$	$N_{\mathrm{jet}} < 2$	4e, 4μ, $2e2\mu$	3 + 3	1-2%	5.1	19.6	[64]
	$N_{\mathrm{jet}} \geq 2$		3 + 3				
$\mathrm{WW} \to \ell\nu\ell\nu$	0/1-jets	(DF or SF dileptons) $\times$ (0 or 1 jets)	4 + 4	20%	4.9	19.5	[65]
	VBF-tag	$\ell\nu\ell\nu + (jj)_{\mathrm{VBF}}$ (DF or SF dileptons for 8 TeV)	1 + 2	20%	4.9	12.1	[66]
	WH-tag	$3\ell 3\nu$ (same-sign SF and otherwise)	2 + 2		4.9	19.5	[67]
$\tau\tau$	0/1-jet	$(\mathrm{e}\tau_h,\ \mu\tau_h,\ \mathrm{e}\mu,\ \mu\mu) \times$ (low or high p_T^τ)	16 + 16	15%	4.9	19.6	[68]
	1-jet	$\tau_h\tau_h$	1 + 1				
	VBF-tag	$(\mathrm{e}\tau_h,\ \mu\tau_h,\ \mathrm{e}\mu,\ \mu\mu,\ \tau_h\tau_h) + (jj)_{\mathrm{VBF}}$	5 + 5				
	ZH-tag	$(\mathrm{ee},\ \mu\mu) \times (\tau_h\tau_h,\ \mathrm{e}\tau_h,\ \mu\tau_h,\ \mathrm{e}\mu)$	8 + 8		5.0	19.5	[69]
	WH-tag	$\tau_h\mu\mu,\ \tau_h\mathrm{e}\mu,\ \mathrm{e}\tau_h\tau_h,\ \mu\tau_h\tau_h$	4 + 4				
bb	VH-tag	$(\nu\nu$, ee, $\mu\mu$, eν, $\mu\nu$ with 2 b-jets$) \times$ (low or high $p_{\mathrm{T}}(\mathrm{V})$ or loose b-tag)	10 + 13	10%	5.0	12.1	[70]
	ttH-tag	(ℓ with 4, 5 or $\geq$6 jets) $\times$ (3 or $\geq$4 b-tags);	6 + 6		5.0	5.1	[71]
		(ℓ with 6 jets with 2 b-tags); ($\ell\ell$ with 2 or $\geq$3 b-tagged jets)	3 + 3				
bb VH-tag (LHCP)		($\nu\nu$, ee, $\mu\mu$, eν, $\mu\nu$, $\tau\nu$ + 2 b-jets) x (low/med/high $p_T(V)$)	10+14	10%	5.0	19.0	

- **Significant changes with respect to ESPG inputs**
  - VH(bb): more channels, full shape analysis, reduced bkg syst, more conservative theory unc.
  - ttH(bb): more conservative treatment of experimental and theoretical uncertainties
  - ttH($\gamma\gamma$): added new analysis
  - Other channels: general improvement in experimental sensitivity

Extrapolation for Top Squarks

1-lepton stop search based on 8 TeV full dataset (20 fb^{-1}): SUS-13-011

- N_{sig} scaled by: $R_{sig} = \sigma_{sig}(14\,\text{TeV})/\sigma_{sig}(8\,\text{TeV}) \times 300\,fb^{-1} / 20\,fb^{-1}$
- Enhancement factors ~4-20 for m_{stop} of 200 GeV – 1 TeV plus a factor of 15 due to lumi

- Conservative extrapolation
  - N_{bkg} & σ_{bkg} scaled by: $R_{bkg} = \sigma_{ttbar}(14\,\text{TeV})/\sigma_{ttbar}(8\,\text{TeV}) \times 300\,fb^{-1} / 20\,fb^{-1}$
  - Background scaled by a constant factor based on ttbar 14 TeV / 8 TeV ratio = (965 fb / 249 fb) = 3.9 plus a factor of 15 due to lumi

- Optimistic extrapolation
  - N_{bkg} is treated same as above, but σ_{bkg} reduced by $1/\sqrt{R_{bkg}}$.
  - (σ_{bkg} dominantly comes from the control sample statistics)
  - Require $\sigma_{bkg} > 0.1 \times N_{bkg}$ (i.e. impose >10% relative uncertainty)

Number of BG events in tightest signal region rising from 3 → 170

Extrapolation for Gluinos

- SUSY search in hadronic (0-lepton) events with MET, at least 3 jets, >=1 b-tags: SUS-12-024.
  - Optimized for T1bbbb, but also has a good sensitivity to T1tttt:
    - Signal regions and control regions are divided in 48 bins of (MET, HT, #b-jets)
    - Maximum likelihood fit in which the "shape" of the backgrounds in the signal region is constrained to that of the control regions
    - Signal "shape" taken from MC
- 8 TeV MC used for the projection with rescaled cross section for SM BG and T1ttt

- Evaluation of significance of each T1tttt point using profile likelihood
- Systematics kept same, but small systematics do not improve results much

Process	8 → 14 TeV
QCD	x 1.05
ttbar	x 3.88
W+jets	x 1.80
Z+jets	x 1.84
gg pair production (@ 1000 GeV)	x ~20
gg pair production (@ 1500 GeV)	x ~60

Scaling for Bottom Squarks

- Search for same-sign dileptons, b-tagged jets, HT, and MET
  - SUS-12-017 published as JHEP03 (2013) 037
- Conservative extrapolation:

Scale N_{sig} by: $\mathrm{R_{sig}} = (300\ \mathrm{fb}^{-1}/20\ \mathrm{fb}^{-1}) \times \sigma_{\tilde{b}\tilde{b}^*}\ (14\ \mathrm{TeV})/\sigma_{\tilde{b}\tilde{b}^*}\ (8\ \mathrm{TeV})$

Scale N_{fake} , σ_{fake} by: $\mathrm{R_{sig}} = (300\ \mathrm{fb}^{-1}/20\ \mathrm{fb}^{-1}) \times \sigma_{t\bar{t}}\ (14\ \mathrm{TeV})/\sigma_{t\bar{t}}\ (8\ \mathrm{TeV})$ (same for N_{flip}, σ_{flip})

Scale N_{rare} , σ_{rare} by: $\mathrm{R_{sig}} = (300\ \mathrm{fb}^{-1}/20\ \mathrm{fb}^{-1}) \times \sigma_{t\bar{t}W}\ (14\ \mathrm{TeV})/\sigma_{t\bar{t}W}\ (8\ \mathrm{TeV})$

- Optimistic extrapolation:
  - Reduce 50% systematics for fakes and rare processes to 40% and 30% respectively.

Search for EWKinos

- Include searches for neutralinos, charginos, and sleptons with 4-leptons, 3-leptons, 2-leptons + jj, etc: SUS-12-022 (HCP)

- For the 14 TeV projections, focus on the search with WZ in the final state
  - There are 120 3-lepton channels and 5 2-lepton+2-jet channels
  - Use 10 most sensitive bins in the 3-lepton channel for multi-channel counting experiment
  - One channel significance: Z=S/sqrt(B+(δB)2)
  - Combined significance from multiple channels
    - $S_i = L \times \sigma \times \varepsilon_i$, $i = 1..N_{channels}$
      - Zi=Si/sqrt(Bi+(δBi)2) = L×σ/sqrt((Bi+(δBi)2)/εi2)
        - o every channel measures L×σ with uncertainty
          - δi= sqrt((Bi+(δBi)2)/εi2)
        - o combined uncertainty
          - $1/\delta_{combined}^2 = \Sigma 1/\delta_i^2$
    - $Z_{combined} = L \times \sigma / \delta_{combined}$

CMS Delphes Studies

- Delphes v3
  - More realistic treatment of pile-up
  - In some cases utilizing Snowmass LHE files, many thanks to the Snowmass Delphes crew
- Simulate Phase 1 CMS detector and Phase 2 options for comparison
  - Phase 1 detector with aging
    - New pixel detector
    - Geometry, efficiencies, and resolutions as best estimated for Phase 1 detector
  - Phase 2 options
    - New tracker (barrel + endcap)
    - Extended tracker (very forward tracking)
    - Endcap ECAL replacement and HE retro-fitting
    - Simulate HF radiation damage by excluding $|\eta| > 4.5$
    - Full replacement of Endcap: ECAL and HCAL (active element and absorber)